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# The Effect of Problem-Solving Video Games on the Science Reasoning Skills of College Students

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The Effect of Problem-Solving Video Games on the  
Science Reasoning Skills  
of College Students

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Running Head: SCIENCE REASONING & VIDEO GAMES

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### ABSTRACT

As the world continues to rapidly change, students are faced with the need to develop flexible skills, such as science reasoning that will help them thrive in the new knowledge economy. Prensky (2001), Gee (2003), and Van Eck (2007) have all suggested that the way to engage learners and teach them the necessary skills is through digital games, but empirical studies focusing on popular games are scant. One way digital games, especially video games, could potentially be useful if there were a flexible and inexpensive method a student could use at their convenience to improve selected science reasoning skills. Problem-solving video games, which require the use of reasoning and problem solving to answer a variety of cognitive challenges could be a promising method to improve selected science reasoning skills. Using think-aloud protocols and interviews, a qualitative study was carried out with a small sample of college students to examine what impact two popular video games, *Professor Layton and the Curious Village* and *Professor Layton and the Diabolical Box*, had on specific science reasoning skills. The subject classified as an expert in both gaming and reasoning tended to use more higher order thinking and reasoning skills than the novice reasoners. Based on the assessments, the science reasoning of college students did not improve during the course of game play. Similar to earlier studies, students tended to use trial and error as their primary method of solving the various puzzles in the game and additionally did not recognize when to use the appropriate reasoning skill to solve a puzzle, such as proportional reasoning.

## CHAPTER 1: INTRODUCTION

Students of today need to be able to adapt to a rapidly changing technological world. They need to have skills and abilities to succeed in this new world and develop solutions for problems yet unknown. Students are unlikely to work for one company their entire working career and will most likely have multiple jobs in a multitude of areas (Fisch & McLeod, 2007). Therefore students must have skills that can be transferred among a variety of situations and contexts as well as enabling them to adapt.

These skills, often referred to as 21<sup>st</sup> century skills (Partnership for 21<sup>st</sup> Century Skills, 2011), are grounded in formal reasoning skills. When these skills are properly cultivated, they can help students become better scientific reasoners and more systematic problem solvers in a variety of contexts. Students need to be able to critically review and reflect on information, draw conclusions, creatively solve problems, and to use different kinds of reasoning to address new challenges. In essence, students need to be able to interact in a highly technical society in a scientific way.

According to Bloom's Taxonomy (1956), higher order thinking skills include synthesis and evaluation. The push to develop higher order thinking skills can be seen in pre-college education as more and more curricula attempt to promote analysis and evaluation as opposed to recall or just comprehension of knowledge. Nowhere is this changed emphasis more important than in the science curriculum. Science is more than a collection of facts; it is a process or a way of thinking (Cavanagh, 2008). The *National Science Education Standards* from the National Research Council (1996) reflect the need for higher order thinking skills and incorporate these critical thinking skills at all levels in the standards for curriculum.

What forms the basis for critical thinking skills? Where do critical thinking skills originate? How do they develop? According to Leighton (2004), reasoning forms the basis for critical thinking skills. Reasoning works to coordinate ideas and to help draw conclusions. It is from those conclusions that one then applies critical thinking skills to solve problems. Therefore, according to Leighton (2004), issues with problem solving often are not due to poor problem solving practices, such as not reading the problem carefully, but are the result of bad or faulty reasoning, such as making unsupported assumptions. When the wrong conclusions are drawn, problem solving is set back.

Unfortunately, traditional science education appears to be failing to help students become scientific thinkers and develop formal reasoning skills as the emphasis is placed on specific content rather than general problem solving or thinking strategies. When a student is able to think scientifically, it almost seems as if it were by accident, rather than the result of any concentrated effort of formal science education. Formal science education too often focuses on content and lower-level knowledge, rather than inquiry and higher-order thinking (O'Neill & Polman, 2004).

Why is this? One of the many reasons why pre-college and undergraduate college students may fail to develop science reasoning is a dislike for formal science and science education courses. Papert (1998) proposes that the children do not like school because they think it is hard, rather they dislike school because it is boring. According to Papert (1998), as long as it is interesting, children actually prefer things that are hard, and in fact can be a source of fun for them. Moreover, the present pedagogical approach to teaching science in most formal educational settings fails to relate to most learners. The information is presented in such a way that students fail to comprehend or even recognize

the big picture of why they are even taking a science course. This has been a problem since the time of Dewey (1910), who argued that science should be more than a collection of isolated facts, but rather should be about developing a scientific attitude and scientific state of mind as well as developing an interest and curiosity about science. Dewey (1910) concluded that the current science pedagogical practices of his day had the opposite effect than intended. O'Neill & Polman (2004) also discuss how science is taught more as content instead of process, leading to students who know bits and pieces about science or have little understanding as to how it is conducted or how science content is connected inside and outside of science. One fundamental reason that college students severely dislike formal science education is because they feel they are unsuccessful with what is called "science" in the educational context. They are unsuccessful in formal science education because they do not know how to think like scientists, nor have they developed science reasoning skills. If we can help students develop their science reasoning skills, they could possibly do better in science, which may have the possible side benefit of improving their attitudes towards science and of having thinking skills that are transferable to a wide variety of contexts.

### **Role of Reasoning in Science**

What role does reasoning play in science and science inquiry? The ability to reason scientifically has been identified as a predictor of success in advanced science classes such as physics (Bitner-Corvin, 1987). These science reasoning skills are necessary for other subjects and can be generalizable across disciplines (Bitner-Corvin, 1987). Lawson (2004) supports the idea that reasoning is critical to science and understanding the nature of science, going as far as proposing that the brain may be hard-

wired for certain kinds of reasoning, such as hypothetical-deductive reasoning. Although logical thought is a large component of thinking and reasoning, scientific reasoning is also based on five different aspects of reasoning: correlational, proportional, probabilistic, combinatorial, and control of variables (Bart & Schleisman, 1988).

### **What is Scientific Thinking or Reasoning?**

According Dunbar and Fugelsang (2005), scientific thinking pertains to the mental process or procedures used when engaged in scientific activities, when reasoning about scientific content or the specific types of reasoning used in science. Scientific thinking or reasoning is not one specific skill, but rather a set of general cognitive processes that are applied by the learner to a specific context or situation in an appropriate way. These cognitive processes include such skills as induction, deduction, analogy, problem-solving and causal reasoning (Dunbar & Fugelsang, 2005). Science reasoning also includes aspects of spatial reasoning. Students need to be able to mentally visualize complex concepts such as those found in chemistry and physics.

### **Science Reasoning in Schools**

To what degree are reasoning and science reasoning taught in schools? College students may enroll in formal logic courses. In high school, formal reasoning and logic are part of the geometry curriculum and may only consist of, at most, a week's worth of instruction from the textbook. Science textbooks do not explicitly cover reasoning at all. It could then be inferred that although critical thinking skills are considered crucial, the foundation for critical thinking, reasoning, is often neglected. Students are left to implicitly learn how to reason or depend on their instructors to offer explicit instruction,



which may not occur given the amount of material needed to be covered every year to prepare students for required standardized testing.

The dilemma is how to improve science reasoning in students in a way that is effective, engaging and interactive while enabling them to transfer the skills to different contexts and situations. Unfortunately, most students are not interested in developing science reasoning skills nor are traditional pedagogical approaches likely to interest and engage them. Although science reasoning skills need to be woven throughout the normal science curriculum, they tend to be taught in isolation at the beginning of the year, if they are taught at all, and are never touched on again. The current science curriculum in schools is so stuffed with content (e.g. O'Neill & Polman, 2004) that teachers may not be able to fit specific instruction in science reasoning, as such, into the curriculum. This pressure to cover specific material has increased in recent years due to *No Child Left Behind* and other accountability trends currently being discussed in education.

### **Importance of Reasoning to Society**

Science reasoning is clearly important to being successful in science and its application to real world problems and situations. Why is science reasoning important to society aside from those who become scientists, doctors, or engineers? Many people claim they don't use science in their everyday lives, but they do use the products of science daily.

In our highly technical and advanced society, the average person has a need to understand science and use science reasoning. No matter how hard schools and educators try, they will not be able to educate every student about every aspect of science or issues in science, especially when future problems are unknown. For example, when the baby-

boomers were in school, global climate change was not a concern, whereas now, it is a major concern and topic of discussion. These same baby-boomers, in their roles as lawmakers and business leaders, are being called to make critical decisions involving technical and scientific concepts. If these leaders have good science reasoning and critical thinking skills, they could potentially make well-reasoned decisions. With the rise of the Internet, people have access to all kinds of information. How does one know if that information is accurate? How does the information consumer critically evaluate sources? This is where science reasoning skills are invaluable. Consumers with a solid foundation of science reasoning skills could potentially be able to judge and evaluate information and its source, identifying incorrect reasoning. An example is the current debate about vaccinating children. Many parents do not understand how vaccines work, nor do they have an accurate view of the risks and benefits of vaccinations. If parents had a better foundation of science reasoning skills, they would better understand concepts like correlation, would be able to critically evaluate resources, and be better able to make informed decisions.

In their review of programs to teach thinking, Ritchhart and Perkins (2005) emphasize that good thinking should enable "...us to perform better than we otherwise would by leveraging more effectively what knowledge we do have and helping us to acquire more as we go..." (p. 791). In other words, it may not be possible to make all learners experts in every domain, but it is more than possible to help learners use what knowledge they do have more effectively.

## **Developing Science Reasoning**

If reasoning is so important, how is it developed? Lawson (2005, 2004) believes that humans are born with some rudimentary form of reasoning that becomes more sophisticated as the brain develops and matures. How does this rudimentary reasoning become the reasoning needed for science inquiry? Likely, it is through practice, training and explicit instruction. Other forms of instruction, such as inquiry methods, may also increase reasoning skills implicitly. But are these methods efficient or are there better ways? According to Stuessy (1989), most methods for teaching reasoning fail to improve students' reasoning. Are there different ways or methods to improve science reasoning skills of students?

A potential solution to improve science reasoning is to have students play video games that focus on strategy and problem solving. Students can play the video games at their own pace and in their own time, enabling them to practice whenever and wherever. When students have finished their work during class time, they can take out their video games and practice science reasoning skills for a short time. After all students have reached a certain point in the game, the teacher can guide the class in a discussion of various problem solving strategies and present analogous situations for discussion. The teacher could guide students towards using these skills in science and in other classes, thereby potentially improving their science and general reasoning.

## **Games**

What is a game? There are many definitions of a game. Koster (2005) asserts that games are essentially patterns. Cruickshank and Tefler (1980) define games as contests with rules that all players must follow. A similar definition is given by Heinich,

Molenda, Russell, & Smaldino (2002) except their definition includes reaching a goal of some kind. Another set of authors defines a game as "...a set of activities involving one or more players. It has goals, constraints, payoffs, and consequences. A game is rule-guided and artificial in some respects. Finally, a game involves some aspect of competition, even if that competition is with oneself" (Dempsey, Lucassen, Haynes, & Casey, 1996, p. 3). Most of the game literature defines games in terms of their characteristics. According to Alessi and Trollip (2001), games share the following characteristics:

- Goals
- Rules
- Competition (or Collaboration/Cooperation)
- Challenge
- Fantasy
- Safety
- Entertainment.

Not all games will have all these characteristics, but they will have the majority of these characteristics, even if the type of game varies greatly.

Gredler (2004) discusses how games and simulations have been used for educational purposes since the 1600s, if not earlier, mostly to simulate war. Crawford (2011) argues that games have always had an educational purpose and that most species learn through games. By the late 1950s, the use of games and simulations spread to other disciplines such as business and medicine. Gredler (2004) points out that games are widely accepted in elementary education, but as the student gets older, the use of games

in education declines, mostly because of the interests of teachers and parents. Papert (1998) argues that games should not be used to teach children "old-fashioned basic skills" (p. 89), such as basic math skills like addition and subtraction, but should be used to teach children how to learn. Games can also be used to encourage creativity in students by having them design their own games.

### **Science Reasoning and Games**

According to Koster (2005), the human brain is pattern-driven and works by attempting to fill in the blanks based on already known patterns. Games are essentially puzzles wherein the brain attempts to learn the underlying pattern, chunk or break it into meaningful pieces and then rerun the pattern until it becomes a routine. Games are exercise for the brain, helping the player practice for real-life challenges (Koster, 2005).

Pillay (2003) argues that recreational computer games consist of the same schema necessary for future learners and workers to be successful, as well as in general academic settings. In recreational computer games, players use a variety of processes such as recursive thinking, organizing and analyzing information, and generating alternative solutions, in addition to developing parallel processing abilities (Pillay, 2003).

According to Squire and Jan (2007), the way learning occurs in video games is most representative of the culture in the new knowledge economy that is interactive and changing. Be aware though that there are many types of computer or digital games. The amount and type of thinking and reasoning necessary for the different games can vary widely between genres.

The learning outcomes from educational video games include: 21st Century Skills, deduction and hypothesis testing, complex concepts and abstract thinking and

finally, visual and spatial processing (Dondlinger, 2007). Therefore, it seems logical that the right type of game, one that is geared towards problem-solving and reasoning, would be beneficial to help students develop and improve scientific thinking skills, specifically those skills related to hypothetical-deductive reasoning and spatial reasoning or ability.

There are a variety of studies examining the use of games and simulations to increase the science content knowledge of students (cf. Clark, Nelson, Chang, Martinez-Garza, Slack & D'Angelo, 2011) and there are studies that use specific types of board games, such as Mastermind, to improve the thinking or reasoning skills of learners (cf. Tornkvist, 1981). More recent research has focused on what can be learned and what is being learned in popular role playing games such as Final Fantasy. There are a variety of descriptive papers that discuss how games, especially digital games, can increase thinking skills. Zemke (1997) argues that games can help players develop logical thinking and deductive reasoning. However, to date, no studies examined and included in this literature review have looked at the use of digital games, especially games available for portable gaming systems, in improving the science reasoning abilities of college students.

### **A New Approach**

Traditional methods and approaches have not encouraged significant improvement in science reasoning skills, so a new approach is warranted. One possible and promising approach is to use digital game-based learning to develop games and simulations that focus on science reasoning skills. Prensky (2001), Shaffer (2006), Gee (2003) and Van Eck (2007), all advocate the use of digital games in learning. Prensky (2001) discusses how current educational practice is failing to meet the needs of the

current generation of students, who are different from previous generations of students in fundamental ways. Prensky (2001) argues that today's students tend to multi-task and use parallel process information in contrast to previous students who processed information in a sequential, linear fashion. For example, web browsing, with all of its links, encourages multi-tasking and parallel processing. He argues that this has caused some loss of logical thinking in current students and recommends using digital games that utilize complex thinking tasks to improve logical thinking (Prensky, 2001).

### **Statement of the Problem**

Many students lack science reasoning skills and the associated critical thinking skills along with the ability to apply these skills to different situations. To be successful learners, students need science reasoning and critical thinking skills. Two important aspects of science reasoning are hypothetical-deductive reasoning and spatial reasoning.

### **Research Questions**

1. In what ways do problem-solving video games affect the reasoning of students and problem solving?
  - a. Do playing problem-solving video games help students develop their science reasoning?
  - b. Do playing problem-solving video games help students increase spatial reasoning?
2. What cognitive processes do students of different levels of reasoning use when playing problem-solving video games?
3. What are the differences in effective game play based on level of experience?

- a. What similarities and differences are observed between expert and novice game players in terms of cognitive processes and game play?
- b. What game behaviors observed in successful game play are successful in improving science reasoning skills?

### **Delimitations**

It is assumed that the college students selected for the study will be capable of formal operational thought; in that their brains will have developed the neuro-biological capabilities for such thinking and does not explore the possible connection of science reasoning skills with intelligence. This study looks at students playing games individually; therefore it does not take into account any social learning that could occur. This research study is limited to the time it takes students to complete two video games, however, improvement in science reasoning, especially analogical and spatial reasoning, may require a longer period of time to be realized. Finally, this study assumes that science reasoning can be assessed with an appropriate instrument and that it will measure the same science reasoning skills that are developed through playing problem-solving video games. This assumption can be supported by careful development or selection of the instrument and ensuring that the science reasoning skills on the testing instrument are well correlated to the science reasoning skills developed by problem-solving games.

### **Significance of Study**

Students need science reasoning skills not only to succeed in science courses, but also to increase science literacy to be able to make informed decisions about complex science issues presented for public deliberation. Additionally, the reasoning skills developed using specific problem-solving video games can be applied to other content



areas, thereby improving students' skills and achievement in additional areas. Students who have better reasoning skills are in a position to become better problem solvers and better decision makers and better citizens. Finally, video games that emphasize problem solving are a simple and fun way for students to develop critical science reasoning skills. By making the development of science reasoning skills fun, students may choose to continue working on developing these reasoning skills when they would otherwise not engage in such activities.

## DEFINITIONS

*Analogical reasoning:* The reasoning that uses the knowledge of a familiar problem, situation or experience to solve an unfamiliar problem (Robertson, 1999).

*Critical thinking:* Although there is no universal definition, critical thinking skills involve the use of interpretation, analysis, evaluation, and inferences to make decisions (Bitner, 1991). Critical thinking skills are often used interchangeable with thinking skills.

Critical thinking refers to the cognitive processes that compose the upper levels of Bloom's Taxonomy and are used to generate and evaluate information. Additionally, critical thinking involves not only having the skills, but continually using said skills to influence cognitive processes and behavior. Critical thinking is context independent.

*Deductive reasoning:* The reasoning that uses knowledge already known to make an inference about a specific case (Robertson, 1999).

*Evaluation:* The highest level in the cognitive domain of Bloom's Taxonomy. Students who possess evaluation skills are able to make and justify decisions and choices depending on the context involved.

*Formal operational:* The ability to perform logical operations on the contents of a mental representation. At this level, thinking becomes more strategic (Lawson, 1985). Specific reasoning skills, such as probabilistic and correlational reasoning, should be present (Bitner, 1991).

*Formal reasoning:* Reasoning that uses the tasks and rules of formal logic and the tasks in formalized systems. Formal reasoning uses deductive reasoning (Nickerson, 1991).

*Game:* An activity, that is fun for the participant, that involves competition, rules and a challenge. Games can be thought of as puzzles and as a type of a cognitive tool.

*Hypothetical-deductive reasoning:* Hypothetical-deductive reasoning is often times known as scientific reasoning. Hypothetical-deductive reasoning is a characteristic thought pattern of those who have achieved formal operations or formal reasoning. This type of reasoning involves the use of strategies to solve problems. When using hypothetical-deductive reasoning, the reasoner will propose a hypothesis and develop experiments to test the hypothesis. The hypothesis is accepted or reworked based on the results of the experiment.

*Inductive reasoning:* The reasoning used in the forming of concepts and in generalizations to make predictions (Nickerson, 1991). Inductive reasoning is the basis of all learning (Robertson, 1999).

*Informal reasoning:* Reasoning that is used in practical situations and everyday life. Informal reasoning involves the use of inferences and induction. Informal reasoning is used to justify beliefs and explain observations (Nickerson, 1991).

*Problem-solving video games:* A genre of computer games, specifically video games, which emphasize the use of reasoning and thinking to solve the various challenges in order to win the game. Problem-solving video games should not emphasis random guessing to win, but rather require strategies of some kind.

*Science reasoning:* Reasoning needed to successfully participate in scientific activities from research to reading scientific reports. Science reasoning is composed of a variety of reasoning skills such as hypothetical-deductive, correlational, proportional, control of variables and spatial reasoning. Science reasoning can be thought of as a set of general cognitive processes used with problems in the context of science.

*Simulation:* An activity that resembles an activity that occurs in real life. A simulation is a simplified version of a real-world activity often used to teach skills and processes when the real-world activity is too complex or dangerous. Simulations can also be a type of game.

*Spatial reasoning:* Spatial reasoning is the ability to mentally rotate shapes and to visualize the object's orientation with respect to self. It is also the ability to mentally create or rotate objects from descriptions.

*Synthesis:* Ability to gather information or pieces of knowledge from a variety of sources to create a new mental schema or product. This is the second highest level in Bloom's Taxonomy in the cognitive domain.

## CHAPTER 2: LITERATURE REVIEW

This literature review explores formal operational thought, such as hypothetical-deductive reasoning, and spatial reasoning, followed by a discussion of previous attempts at teaching thinking. The review examines multiple viewpoints on games, including a discussion on the difference between simulations and games. Games are defined and theoretical justification of the use of games in education is reviewed. The use of games in science and science education is discussed, as well as using games to develop cognitive processes and science reasoning. This discussion will touch upon teaching with games and evaluating games for teaching and learning.

### **Science Reasoning**

What is science reasoning? What cognitive skills and processes are needed in science reasoning? This section defines science reasoning, and discusses the development of this reasoning and its importance to science.

Using the Collegiate Assessment of Academic Proficiency, a college-level ACT, Rifkin and Georgakakos (1996) gave the Science Reasoning Test to two groups of students at a community college using a pre-post test design. The Science Reasoning Test on the ACT requires students to understand, analyze, and generalize a variety of passages while using problem-solving and reasoning skills (ACT, 2007). Over the length of a semester, it was demonstrated that college science classes positively influenced science reasoning skills, with the effect increasing with the number of classes. It was also shown that physics courses contributed the most to an increase in science reasoning, with the calculus-based physics course having the strongest impact (Rifkin and Georgakakos, 1996). Rifkin and Georgakakos (1996) propose the increase in science

reasoning is due to students in science courses being more involved and spending more energy studying and engaged in other scientific pursuits.

### **Proportional reasoning**

Thornton and Fuller (1981) collected data from over 8000 college students at three different universities, using a different problem requiring proportional reasoning at each university. Depending on the problem and the university, 60%-70% of the students solved the problem in a manner consistent with formal operational thinking (Thornton and Fuller, 1981). Thornton and Fuller (1981) draw a number of conclusions from their study, mainly that college students use a variety of problem solving approaches when solving proportional reasoning problems and that details in the problem itself will influence if and how students will use proportional reasoning. Additionally, instructors should not assume that students use proportional reasoning even when the problem clearly requires proportional reasoning (Thornton and Fuller, 1981).

### **Analogical reasoning**

Analogical reasoning or thinking may be one of the most important reasoning skills for science reasoning and thinking. This involves the use of analogies or familiar problems and patterns to solve a new problem (Robertson, 1999). A person who is faced with a problem may realize that it is similar to another type of problem and may attempt to solve it in the same way. Scientists use analogies to bridge the gap between what they already know and what they are trying to know. It is a crucial method to discovering new scientific knowledge. Analogical reasoning has two components: the target and the source. The source is what is already known or understood while the target is the problem that needs to be explained (Dunbar & Fugelsang, 2005). When using an

analogy, the important elements of the source are mapped onto the important elements of the target, possibly enabling new discoveries.

However, analogy can be difficult for novices to implement. Novices, trying to make an analogy, tend to focus on the superficial relationship between the target and the source, such as color. The expert, however, will use either superficial features or deeper relational features, such as structure or class, depending on the goal of the analogy. What makes expert scientists successful at analogies is their deep understanding of the science content and the relationships within the content, which can then be used in forming analogies (Dunbar & Fugelsang, 2005).

### **Hypothetical-deductive reasoning**

Hypothetical-deductive thinking or reasoning involves hypothesis testing using hypothesis, prediction, and experiment and is thought to be a more advanced form of reasoning as it requires the use of other reasoning skills such as analogical reasoning. Those that have the ability to use hypothetical-deductive reasoning are able to ask questions, predict solutions, sort through the collected evidence and derive conclusions to answer the asked questions and to handle novel situations (Lawson, 1995).

Hypothetical-deductive reasoning follows the pattern of *if...and...then...and/but...therefore* (Lawson, 2000).

Hypothetical-deductive reasoning is important because there is a high correlation between hypothetical-deductive reasoning skills and academic achievement as measured by the Iowa Test of Basic Skills. Therefore, if students are to succeed in education, they will need hypothetical-deductive reasoning (Lawson, 1995). Etkina, Karelina and Villasenor (2007) discuss how examples of hypothetical-deductive reasoning are found in

abundance throughout the history of physics and drives its progress. Lawson (2000) argues that all of the natural sciences, no matter the discipline, are essentially applications of hypothetical-deductive reasoning. Even more importantly, hypothetical-deductive reasoning patterns can be generalized to practical or more real-world type problems (Lawson, 2000). Students with hypothetical-deductive reasoning skills do better on the Force Concept Inventory (Colletta and Philips, 2005).

### **Other types of reasoning**

Informal reasoning is the ability to think through complex issues by evaluating evidence, support and arguments (van Gelder and Bulka, 2000). According to van Gelder and Bulka (2000), informal reasoning is central to critical thinking and is a basic cognitive skill required in most disciplines and in the workforce. Unfortunately, there is little evidence that education in and of itself improves informal reasoning in any effective manner (van Gelder and Bulka, 2000). Van Gelder and Bulka (2000) assert that to improve general informal reasoning skills, there must be quality practice which covers a variety of domains so that the informal reasoning skills are detached from specific content. Van Gelder and Bulka (2000) noticed that many of their university students lacked informal reasoning skills and so developed a software program called Reason! to improve these skills. The software program incorporated elements such as scaffolding, guidance, feedback and exercises of increasing difficulty. Over the course of a semester, students who used the Reason! program had significant improvement (5.84%) over the control group on Watson-Glaser Critical Thinking Appraisal. Reason! provides an efficient environment for students to engage in quality practice in informal reasoning (van Gelder and Bulka, 2000).



Induction may also have a role in science reasoning. While the importance of induction is currently being debated by Lawson (2005) and other researchers, it appears that induction may have a role to play in science reasoning depending on how it is defined. Nickerson (1991) defines inductive reasoning as creating generalizations to make predictions. Others define inductive reasoning as learning from experience (Lawson 2005). Robertson (1999) claims inductive reasoning is the basis of all learning. Induction tends to be a more informal and intuitive type of reasoning while hypothetical-deductive reasoning is more structured, being described by using the formal rules of logic (Nickerson, 1991).

Combinatorial reasoning is the process of generating all possible combinations of a problem to derive a solution. According to English (2005), combinatorics, which is the field of study that uses combinatorial reasoning, can be defined as a way to calculate and arrange objects in a finite set and was developed from studying games of chance. An example would be determining how many different lunches could be constructed given different sandwiches, snacks and drinks. This is an important area of mathematics and science as it can help students understand how to make conjectures and generalizations as well as develop systematic thinking. Furthermore, most probability misconceptions or difficulties with probabilistic reasoning can be traced to a lack of combinatorial reasoning, such as defining the sample space (English, 2005). English's (2005) review of the literature found that students had difficulty recognizing combinatorial problems, let alone solving them using combinatorial reasoning. Having students practice combinatorial reasoning by using novel problems, especially without direct instructor

involvement, and overcoming the sample space misconception, produced improvement in probabilistic thinking (English, 2005).

Another reasoning skill is the process of identifying and controlling variables while solving problems. Many research studies require the ability to identify variables and control the ones that are essential to the solution of the research question.

Probabilistic reasoning consists of the process of generating probability statements, similar to what occurs in statistics. Finally, correlational reasoning is the process of determining if a relationship exists between two ideas or situations (Lawson, 1995). Correlational reasoning is similar to proportional reasoning, in that both are used to determine if a relationship between variables exists.

### **Scientific Thinking Skills**

Scientific inquiry and activity requires both scientific thinking and scientific reasoning skills. Science reasoning includes those specific skill sets to solve problems and evaluate arguments. Science reasoning is one facet of scientific thinking, which can include science process skills in addition to science reasoning.

Dunbar and Fugelsang (2005) review the literature pertaining to scientific thinking and reasoning and define scientific thinking as referring to the cognitive processes used when reasoning about scientific content, when participating in scientific activities, or the specific type of reasoning that is used in science. Scientific thinking includes many different types of cognitive operations that are more general in scope, such as deduction, induction, analogy, causal reasoning and problem-solving (Dunbar & Fugelsang, 2005).

Zimmerman (2007) has conducted a thorough literature review on the

development of scientific thinking skills in students in eighth grade and younger, focusing on the skills needed for scientific inquiry, specifically, hypothesis generation, experimental design, evaluating evidence and drawing inferences. A slightly different definition of scientific thinking defines it as “the application of the methods or principles of scientific inquiry to reasoning or problem solving situations and involves the skills implicated in generating, testing and revising theories” (Zimmerman, 2007, p. 173).

Fully developed scientific thinking skills include metacognitive skills such as the ability to self-reflect (Zimmerman, 2007). According to Zimmerman (2007), there is a large body of evidence to support the claim that investigation skills, such as inquiry skills, and the needed domain-specific knowledge are inter-related to each other, which supports the development of scientific thinking. “Scientific thinking involves a complex set of cognitive and metacognitive skills, and the development and consolidation of such skills require a considerable amount of exercise and practice” (Zimmerman, 2007, p. 213).

### **Science Reasoning, Science Education and Formal Operational Thought**

In this section, formal operations also known as formal operational thought are defined and its theoretical background explored. Next, science reasoning and formal operational thought are related to each other. Finally, the role of science education in developing formal operational thought and science reasoning is discussed.

#### **Formal operations.**

The formal operations stage is characterized by the ability to think in a hypothetico-deductive manner and the ability to consider all possibilities in a complex problem (Bart, 1972). According to Bart (1972), “Formal operations are internalizable, reversible actions which are coordinated in an internalizable system and which are based on

propositions.” (p. 663). Initially, Piaget theorized that formal operation reasoning was reached during the time period between ages 11 and 15 but later revisions theorized that attainment of formal operational reasoning may not occur until sometime between 15 and 20; furthermore, leading Piaget to the conjecture that formal operations may be attained at different times in different areas (Roberge, 1976).

Formal operational thought is characterized by many different cognitive skills; the two major cognitive skill sets are logical thinking skills and scientific thinking skills. Hypothetical-deductive reasoning and the ability to construct hypotheses are the characteristics of logical thinking skills while scientific thinking skills consist of the ability to understand and use specific aspects of reasoning (Bart & Schleisman, 1988). According to Bart (1972), formal thought can be measured using four different assessments: Piagetian tasks, verbal or numerical analogies, reading comprehension tasks, and logic items.

### **Science education and formal operations.**

Collings (1985) argues that formal operations are integral to science education necessary if students are to have any understanding of science beyond observation and recall. Collings (1985) and other researchers argue that formal operational thought is necessary to develop scientific thinking.

Collings (1994) cites Selly (1981) in discussing why the attainment of formal operational thought is so critical for science achievement. Without formal operation thought, students are unable to or have significant difficulty with

- develop systematic analysis of problems;
- suggest possible solutions to problems;

- understand reliability of evidence;
- develop awareness of errors, degrees of confidence;
- develop scientific skepticism and detect bias;
- appreciate the difference between fact and opinion; and
- develop the ability to test a hypothesis (Collings, 1994, Introduction, para. 3).

Without these abilities, students can have difficulty developing scientific thinking skills and other higher-order thinking skills needed throughout their lives (Collings, 1994).

Citing Flavell (1963), Collings (1994) emphasizes that formal operations, such as combinatorial analysis and control of variables, form the cornerstone of more sophisticated scientific abilities than simply recalling information.

Bitner (1991) suggests that for students to be successful in science courses, they need to have all of the reasoning skills that define formal reasoning. These studies also found that students had the most difficulty with tasks that involve correlational reasoning and tasks involving the use of inference (Bitner, 1991). This is significant because as discussed, both of these skills are important pieces of science reasoning.

*Interventions to improve science reasoning and/or formal operational thought.*

It is clear that science reasoning and formal operational thought are critical to success in science and in developing skills needed to be successful as adults. What types of interventions have been developed to improve science reasoning or formal operational thought? How effective are these interventions?

Vass, Schiller and Nappi (2000) conducted a study to determine if giving explicit instruction to college undergraduate education majors would increase their formal reasoning skills in three areas. The three areas of formal reasoning studied and tested

were proportional, probabilistic and correlational reasoning. The researchers found that students who received direct instruction in the three areas of formal reasoning had a significant increase in the ability to solve formal reasoning problems in these areas than students who received no instruction. Students with no mathematics or science background who received instruction made the largest gains in reasoning. Additionally, students who only received instruction in proportional and probabilistic reasoning had similar post-test scores on correlational reasoning as students who received instruction in all three areas. This study also confirmed previous findings that students who have taken more challenging science and mathematics courses will have better reasoning skills than students who have not taken these classes (Vass, Schiller, & Nappi, 2000).

#### **Miscellaneous studies.**

Enyeart, Baker, and VanHarlingen (1980) measured the logical reasoning of university students in an introductory physics class and compared it science achievement. They found that general reasoning ability is significantly correlated with the final physics grade. They determined that deductive reasoning influenced the physics grade more than inductive reasoning, probably because introductory physics is taught using deductive processes (Enyeart, Baker, & Van Harlingen, 1980).

#### **Spatial Reasoning**

Spatial reasoning is sometimes interchanged with spatial ability or spatial awareness. Spatial reasoning can be defined simply as the ability to visualize and transform objects using the imagination (Sorby, Leopold, and Gorska, 1999). In this review, the focus is on spatial reasoning as a skill that can be improved rather than an innate ability. In this section of the literature review, spatial reasoning is defined and its

importance to science is discussed. The review then moves on to discuss differences various groups exhibit in spatial reasoning as well as strategies employed when using spatial reasoning. Finally, miscellaneous research relating to spatial reasoning is presented.

### **Defining spatial reasoning.**

In their review of the literature, Hegarty & Waller (2005), concluded that spatial reasoning is made up of numerous different factors, with three factors (spatial relations, spatial orientation and visualization) being examined most in the literature. Spatial relations and spatial orientation are sometimes grouped together, as they are highly correlated with each other and are defined as the "... ability to understand the arrangement of elements within a visual stimulus, primarily with respect to one's body frame of reference" (p. 125). One problem that Hegarty & Waller (2005) note is that the definitions of the different factors of spatial reasoning are inconsistent across the literature. As cited by Hegarty & Waller (2005), Thurstone (1950) defines spatial orientation as the "... ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem" (p. 127). McGee (1979) (as reported by Hegarty & Waller (2005)) has a broader concept of spatial orientation, which only involves mental rotations, which do not involve the body orientation of the observer. Being able to form mental images of objects when moved to a new position is considered spatial orientation, according to Lord and Rupert (1995). However, the critical difference between spatial orientation and spatial visualization is that spatial orientation requires the changing of the viewpoint or the perspective of the individual while spatial visualization requires the imagining how objects look when moved. Spatial

reasoning and abilities do depend on basic cognitive processes such as processing speed and being able to hold and manipulate an image in working memory (Hegarty & Waller, 2005). Visualization simply requires “the mental manipulation of objects” or changing the mental image in some way (Hegarty & Waller, p. 125, 2005; Lord and Rupert, 1995). According to Sorby et al. (1999), McGee defined spatial visualization “...as the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli” (p. 280).

A common term found in conjunction with spatial reasoning is visuospatial reasoning. According to Halpern and Collaer (2005) visuospatial involves information that is visual in nature, in other words, it stimulates the eye, and information that has spatial properties involving the relationships between objects and objects in a space. This information can be new or can be pulled from memory and can be generated by more than the visual system, such as touch or sound. Additionally, these spatial representations do not necessarily have to be pictures; they can be schematic or symbolic (Halpern & Collaer, 2005). According to Lord and Rupert (1995), visual-spatial thinking occurs when “one imagines a written word, formulates an idea, predicts a strategy or the outcomes of an event, or plans or designs something” (p. 48). It is the ability to create and then manipulate if needed, an image in the mind derived from words or thoughts (Lord and Rupert, 1995).

The United States Employment Service (1957) defines visuo-spatial understanding “as the ability to juxtapose, manipulate, and orient an object mentally and to create structures in the mind from written and verbal directions” (as cited by Lord, p. 396, 1985). Mayer (2005) defines visuospatial thinking as occurring when a mental image is formed and manipulated in a principled manner and involves both content and



process. Casey, Andrews, Schindler, Kersh, Samper, and Copley (2008) provide the simplest definition of spatial reasoning “the ability to think and reason through the comparison, manipulation and transformation of mental pictures” (p. 270).

### **Why is spatial reasoning important?**

According to Hegarty and Waller (2005), spatial reasoning is important for many everyday activities such as going from place to place and is important for several career paths, most notably, pilots and engineers and correlates with success in mathematics and science. Halpern and Collaer (2005) emphasize that visuospatial reasoning is needed for a wide range of cognitive tasks, for example rotating objects and visualizing written descriptions. Mayer (2005) asserts that visuospatial thinking or reasoning during learning can increase the understanding of the learner because it is needed by the learner to help construct knowledge. Casey, et al. (2008) suggest that spatial reasoning can assist or even be used instead of logical or deductive reasoning when solving problems, especially in the mathematical domain. Based on the literature, Lord (1985) suggest that a lack of spatial reasoning skill can even impair the creative thinking abilities of an individual.

### **Differences in spatial reasoning.**

There are differences between people’s ability to reason spatially. The literature frequently discusses gender differences found in spatial reasoning. However there are differences found within gender. One difference between high and low spatial reasoners is the quality of the image being held in working memory. Low spatial reasoners will lose information while trying to rotate an object and can require several attempts to complete the task. Therefore, one major difference between high and low spatial

reasoners are the resources available for spatial processing and storing in working memory. Another major difference is that high spatial visualizers tend to create schematics or diagrams and are more successful at solving problems than low spatial visualizers who tend to create pictures when solving problems (Hegarty & Waller, 2005). Hegarty and Waller (2005) report a puzzling and apparently contradictory result from the literature; that while spatial reasoning is correlated with mathematics and physics performance, visualizers are not more successful at solving these types of problems, because they tend to rely on analytic strategies rather than spatial strategies to solve the problems.

The review by Halpern and Collaer (2005) discusses the sex differences found using some assessments of spatial and visuospatial reasoning. Overall, males are better at spatial reasoning than females and the degree of difference depends greatly on the assessment and the specific aspect of spatial reasoning involved as well as the specific cognitive processes needed to perform the spatial reasoning tasks. Along with differences in means, there are also differences in male scores on spatial reasoning assessments showing more variability than those of females. The largest sex differences (between .9 and 1.0 standard deviations) are seen in mental rotation tasks; those tasks that require a three-dimensional figure to be manipulated in working memory. Indeed it is the sex differences in spatial reasoning that may be a contributing factor to the observed sex differences in mathematics achievement which are eliminated when spatial reasoning ability is statistically controlled for (Halpern & Collaer, 2005).

### **Strategies Used in Spatial Reasoning.**

Individual differences in spatial reasoning can often be attributed to the different strategies used by the reasoner. Just and Carpenter (1985) (as cited by Hegarty & Waller, 2005), identified, using verbal protocols, three different strategies for solving the problems in the Cube Comparisons Test, which assesses spatial orientation and spatial visualization. Instead of using a spatial orientation strategy, reasoners will often use a mental rotation strategy, attempting to move to a new perspective or vice versa (Hegarty & Waller, 2005). What Just and Carpenter (1985; as cited by Hegarty & Waller, 2005) found was that low spatial reasoners rotated the cubes around an axis that was orthogonal to the cube face while high spatial reasoners rotated the cubes around noncanonical axes, meaning a high spatial reasoner could complete a task with fewer mental rotations than a low spatial reasoner.

Lajoie (2003) points out that previous research has found that there are two effective strategies used in spatial reasoning tasks. In the first strategy, the constructive approach, the reasoner mentally creates or constructs visual representations of objects requiring a transformation of some kind. In the constructive strategy, which is a step by step method or strategy, the reasoner uses feature decomposition, rotating, folding and orientating, and finally hypothesis generation and testing. In the second strategy, the analytic strategy, the reasoner compares and then transforms the object by features (Lajoie, 2003).

### **Improving spatial reasoning.**

According to Halpern and Collaer (2005), visuospatial information processing improves with practice and instruction, suggesting that spatial reasoning can be

improved. Additionally, both sexes can benefit from participating in activities that build or develop spatial reasoning. Finally, the research seems to indicate that experience with spatial activities, such as building with blocks, or experience gained from work-related activities can also improve spatial reasoning (Halpern & Collaer, 2005).

### **Research in spatial reasoning.**

Lajoie (2003) conducted two studies of spatial reasoning. The first study was a cognitive task analysis, also known as a process-analysis, of the orthographic projection task, which is a two-dimensional representation of a three-dimensional object, for example, a blueprint and the associated building. Lajoie (2003) used expert and novices spatial reasoners in a protocol analysis to determine the strategies used to solve orthographic projection problems and assessed spatial reasoning using the Paper Folding Test, the Surface Development Test and orthographic projection problems similar to those found in mechanical engineering textbooks. In line with the research on the differences between experts and novices, Lajoie (2003) found that experts had more hierarchically based representations and highly organized mental representations of objects than novices. Additionally, experts had more schemas that they could call upon when solving the orthographic projection tasks than novices, who tended to use a mix of the constructive and analytic strategies (Lajoie, 2003).

In the second study, Lajoie (2003) examined whether spatial reasoning could be taught using a computer-based learning environment. The tutor, OPT, was designed to build on the prior knowledge of learners using bite-sized architecture (Lajoie, 2003). After performing appropriate statistical analysis, Lajoie (2003) found that undergraduate students who used the OPT tutoring program increased their ability to perform

orthographic tasks and that low spatial reasoners benefited more from the tutoring than high spatial reasoners.

Casey et al. (2008) investigated the effect of building block activities on the spatial reasoning of kindergartners. Block building helps develop spatial visualization and mental rotation (Casey et al., 2008). They conducted three interventions, block building embedded into a story context, block building without a story context and a control condition. Instead of a paper and pencil two-dimensional test of mental rotations, the researchers built the objects to be rotated using multi-link cubes. Casey et al., (2008) found that both block building interventions increased the spatial reasoning of the kindergartners significantly, with the block building embedded in a story intervention being most effective.

Lord and Rupert (1995) measured visual-spatial aptitude in science and math elementary education students in their sophomore and junior years. Using the Paper Folding Test and the Cube Comparison Test, Lord and Rupert (1995) found that the elementary education majors in the sample scored significantly lower than the average provided by the test norms. However, the students that were majoring in elementary math education and elementary science education scored significantly better than the rest of the sample and the normalized averages (Lord & Rupert, 1995). Lord and Rupert (1995) conclude that students who have high spatial reasoning skills gravitate towards science and math careers and additionally, experience in the math and science courses helps develop the spatial reasoning skills of these students.

Sorby, Leopold, and Górska (1999) measured the spatial reasoning skills of engineering students in the United States, Germany and Poland using the Purdue Spatial

Visualization Test: Rotations (PSVT:R), the Mental Rotations Test (MRT) and the Mental Cutting Test (MCT). The researchers found significant gender differences at each university (Sorby et al., 1999). For the German students, previous experience, such as vocational training or types of play such as building blocks, was more significant for females than for males. Sorby et al. (1999) concluded that gender differences can be traced to males participating in those activities that build spatial reasoning skills such as building blocks whereas females are less likely to participate in these activities, thereby not developing their spatial reasoning.

Lord (1985) conducted a pre-post experiment using 84 undergraduates enrolled in a biology class that were randomly placed into a control and an intervention group. The spatial reasoning of the students was measured using the spatial measures from the Educational Testing Service's Kit of Factor Referenced Cognitive Tests. The intervention was designed to impact both spatial visualization and spatial orientations and was conducted over the course of an academic semester once a week during the laboratory time. The intervention consisted of giving students various geometric figures to manipulate and having them visualize the different surfaces that would result if a plane was to intercept or transverse the geometric figure at different angles. Lord (1985) found there were significant increases in spatial abilities between the pre- and post-test for the experimental group but not for the control group. Additionally, the intervention improved the understanding of the experimental group of spatial matters and their ability to work with a mental image. The only area where there was not improvement was in the field independency area, the flexibility of closure task (Lord, 1985). He (1985) concluded the reason for this was because the sample consisted of science students, who

already have higher spatial reasoning abilities and proposes there will be a difference between science and nonscience students.

### **Relationship between Hypothetical Deductive and Spatial Reasoning**

Before discussing hypothetical-deductive reasoning, what is the connection between spatial reasoning and other types of reasoning? Wheatley (1990) discusses the importance of spatial reasoning to mathematics. He argues that mathematics is essentially the establishing of patterns and relationships requiring spatial reasoning to accomplish. Accordingly, because it compliments analytical reasoning, spatial reasoning is crucial for success in mathematics, especially advanced mathematics and geometry (Wheatley, 1990).

Moses (1980) examined the sex and age related differences and the impact of visualization instruction on spatial reasoning, deductive and inductive reasoning and problem-solving. The hands-on instruction focused on the three facets of visual thinking: seeing, imagining and drawing. Morris (1980) found that there was a correlation between problem-solving performance, the Mental Rotations Test and the Reasoning Test. The visualization instruction did improve spatial and reasoning ability (Morris 1980).

Piburn (1980) conducted a study examining the correlation between formal thought and spatial reasoning using thirty-four 6<sup>th</sup> form (high school senior) students from New Zealand. Piburn (1980) used Piagetian tasks measuring proportional reasoning, specifically the Shadows Task and the Balance Task, and the Surface Development Test and the Card Rotation Test to measure spatial reasoning and found a significant correlation ( $r=.42$ ,  $p\leq.05$ ) between the Piagetian tasks and the Surface Development task. There was also a significant correlation between the school certificate

(science) and the Surface Development Test ( $r=.41$ ,  $p\leq.05$ ) and the school certificate (science) and the Piagetian tasks ( $r=.34$  and  $r=.36$ ,  $p\leq.05$ ) (Piburn, 1980). Piburn (1980) asserts these results support the claim that the proportionality schema of Piaget involves some aspect of spatial reasoning ability, differentiating proportional reasoning from the other formal reasoning skills or elements. This study is significant because it suggests improving spatial reasoning may improve formal reasoning, especially proportional reasoning. It also suggests that it may be prudent to include spatial instruction and tasks when attempting to improve science reasoning skills of students.

### **Teaching Thinking**

There have been numerous programs and curricula designed to improve thinking or reasoning skills throughout the last few decades. Some of these programs have been successful and some have not. The focus is now on past efforts to teach thinking or reasoning focusing on why or why not a given approach was successful.

Ritchhart & Perkins (2005) discuss five challenges when attempting to teach thinking. The first challenge is whether or not thinking can be successfully taught. The second challenge is defining good thinking. The third challenge to teaching thinking involves developing the proper attitude or disposition towards thinking. The fourth challenge involves transfer. Finally, the fifth challenge is concerned with the development of cultures of thinking in a classroom (Ritchhart & Perkins, 2005).

Ritchhart and Perkins (2005) briefly review some interventions to teach thinking while addressing some of the concerns when attempting to teach thinking skills. First, Ritchhart & Perkins (2005) discuss the need to teach thinking. Although given a rich environment students will learn how to think and that formal education will improve



these basic thinking skills, it is not enough to ensure that higher-end thinking develops, hence the need to teach and learn thinking. One problem is that certain types of thinking are not natural to us. Ritchhart & Perkins (2005) give the example of probabilistic thinking, which is counterintuitive and often does not mesh with previous experience. Additionally, the innate thinking of an individual can inhibit more effective ways of thinking. Ritchhart & Perkins (2005) conclude that good thinking does not automatically develop naturally. Although thinking occurs naturally, thinking skills and processes can be improved and made more precise and formal (Ritchhart & Perkins, 2005).

Wilson (2000) conducted a short review of the literature on teaching thinking skills to children more effectively, using both British and American databases, and found that thinking skills have been primarily taught in one of two ways. The first method uses specific programs designed to teach thinking skills, while the second method embeds the thinking skills into the regular curriculum. The effectiveness of these methods were mixed (Wilson, 2000).

Lawson (1993) examined what levels the teaching of thinking is effective despite arguing that thinking skills cannot be directly taught nor can they be directly learned. According to Lawson (1993), thinking skills develop when students are put into situations in which they struggle to answer questions and must reflect on the answers and the process of getting the answer. Students need mental disequilibrium, reflection and repetition to become aware of their thinking and to be able to apply the thinking to new situations and concludes that more than concrete thinking skills should be focused on in the early grades with focus shifting to formal thinking skills in high school. Instead, alternative hypothesis testing and other formal thinking skills should be used and

encouraged at all grade levels. The skills focused on should not vary across ages, but rather the context in which those skills are used should be age appropriate (Lawson, 1993).

Sanz de Acedo Lizarrago, Sanz de Acedo Baquendo, Mangado and Cardelle-Elawar (2009) define thinking skills as reasoning, creativity, problem solving and decision-making. They conducted a study using 13-year-old students to determine whether separate specific curriculum on thinking skills were more effective than having the thinking skills infused throughout the curriculum, known as the infusion method. Effectiveness was measured using a variety of instruments that measured thinking skills, creativity, self-regulation and academic achievement. The conclusion from three separate research studies indicated that the infusion method of teaching thinking skills is the most effective (Sanz de Acedo Lizarrago et al, 2009).

## **GAMES**

### **Defining a Game**

Before discussing using games to develop science reasoning skills, a definition of what a game is must be constructed as different researchers define games differently. Commonly in the research, a game is not defined but rather is constrained by a set of parameters or characteristics. However, many of these definitions have elements in common such as competition, rules and challenge.

In his book “A Theory of Fun For Game Design,” Koster (2005) gives an overview of the differing definitions of game found in the literature. These definitions range from a series of meaningful choices, to an activity with rules, to a series of challenges in a situated environment (Koster, 2005). Koster (2005) notes that these various definitions do not include fun, which he argues is a critical element of a game and

adds to his definition of game the idea that games are puzzles to solve. What the brain does, when confronted with a game, or puzzle, is to learn the underlying pattern, chunk or break the pattern into meaningful bits, file those bits away for further use and then rerun as necessary. Games are unique because they are already chunked for our brains. In other words, games have patterns to them that are already broken or chunked in a way that the brain prefers. Unlike the real-world which requires more mental work, games are already formal systems without distracting details and are already abstract, making them easier for the brain to manipulate (Koster, 2005). This is in contrast to abstract concepts like algebra, which require some kind of mental schema and previous knowledge or context. Simply put, “games serve as very fundamental and powerful learning tools” (Koster, 2005, pg. 36). Koster (2005) expands his definition of a game to include the concept that a good game teaches everything it has to offer before the player stops playing. To summarize, Koster defines a game as a fun puzzle to solve that teaches critical information early in the game.

Another relevant definition of game comes from Hogle (1996) who proposes games as cognitive tools. Cognitive tools allow a learner to perform a cognitive task that would otherwise be beyond their abilities, such as calculators. A cognitive tool enables the learner to become a better thinker as they allow the learner to focus on higher order thinking skills, such as synthesis, rather than lower order thinking skills, like recall. Hogle (1996) builds on the idea of games as cognitive tools by first discussing the idea of a cognitive toy, a type of cognitive tool that is fun and engaging, thereby defining an educational game as a type of cognitive tool.

Although the definitions of Koster and Hogle are the most relevant to this current

research study, other researchers have defined game more rigorously and include elements that are relevant to the current research project.

Gredler (2004) defines games as “experiential exercises that transport learners to another world,” (p. 571) where the players can apply their knowledge and skills to win. The problem with this definition is that some games do not require either skill or knowledge to play or win.

The most common definition of game resembles the definition constructed by Dempsey, Lucassen, Haynes, and Casey (1996), who define a game as "a set of activities involving one or more players. It has goals, constraints, payoffs, and consequences. A game is rule-guided and artificial in some respects. Finally, a game involves some aspect of competition, even if that competition is with oneself" (p. 3). Players play games because they are fun. Any learning that occurs is largely incidental, unless it is needed to make the player better at the game (Dempsey, Lucassen, Haynes, & Casey, 1996). This is in direct contrast to the definitions of Koster (2005) and Hogle (1996), both of whom argue that games are all about learning and purposeful learning at that and also with Papert (1998), who argues that children play games because they are hard fun and subsequently learn. An intrinsically motivating instructional game was defined as a game in which the game structure teaches the instructional content (Dempsey, Lucassen, Haynes, & Casey, 1996).

Besides including competition and reward in the definition of a game, Green and McNeese (2007) expand the definition of a game as having a beginning and an end. Heinrich, Molenda, Russell & Smaldino (2002) further add to the definition the element that the rules in a game differ from the rules in real life.

For this study, the definition of a game will be a conglomeration of the above definitions, incorporating relevant elements. Essentially, a game is a fun activity that involves competition, rules and a challenge. Because games can be considered as puzzles and cognitive tools, it makes them ideal vehicles to improve thinking and reasoning skills.

### **Difference Between Games and Simulations**

One area of the literature that is similar to games is the work dealing with simulations. Some researchers such as Cruickshank and Tefler (1980) define a simulation as a subset of games. Other researchers, such as Heinich et al. (2002), define simulations in such a manner as to completely separate them from games. Other researchers, again, Heinich et al. (2002), combine simulation and game into a new construct, the simulation game.

Simulations are open-ended situations that evolve as different variables interact and the players make decisions (Gredler, 2004). Cruickshank and Tefler (1980) define simulations as "... the products that result when one creates the appearance or effect of something else" (p. 75). Heinich et al. (2002) define a simulation as an abstract or simplified version of a real process or situation in which the learners have a role to play or perform that interacts with other role players in some critical way. In other words, simulations are a way to digitally model real-world events and processes.

The advantages of simulations are that they are realistic; they allow the learner to practice risky activities in a safe environment and simplify a real, complex situation for the learner. Simplification of a complex situation is also a disadvantage of simulations because one can simplify too much, making the simulation no longer realistic.

Additionally, simulations can be time-consuming (Heinich et al., 2002).

A simulation game combines features of both games (usually challenge or competition) and simulations (such as role-playing). According to Heinich et al. (2002), simulation games enable holistic learning, meaning that learners "... encounter a whole and dynamic view of the process they are studying" (p. 35). Another type of simulation game that is gaining in popularity is the cooperative simulation game, in which a group of learners must work cooperatively to succeed at the game (Heinich et al., 2002).

Instead of looking at games and simulations as separate and distinct items, Aldrich (2005) suggests that it is more productive to think about games, simulations, and pedagogy in terms of the elements that can improve the educational experience, when the elements are in the right combination. According to Aldrich (2005), game elements provide entertaining interactions which can increase the enjoyment and increasing the enjoyment means the players will play longer, potentially increasing learning. Surprisingly, he contends that game elements do not directly support the learning objectives, but are necessary to get the learner to interact with the learning objective. Game elements can replace simulation elements in order to keep the engagement fun (Aldrich, 2005).

### **Types of Games**

Are all games essentially the same, or can they be divided in some meaningful way by their characteristics?

One way to organize games is to categorize them by how they are used. Cruickshank and Tefler (1980) divide games into academic, or games primarily for learning, and non-academic, games primarily for fun. Academic games can further be

broken into simulation games and non-simulation games. Non-simulations games are those games in which the content of a specific subject is used to solve problems (Cruickshank & Tefler, 1980). Simulations are games in which the players play in a simulated environment with the goal of providing players with some kind of insight pertaining to real-world processes.

Some researchers further classify academic games into edutainment and educational games. Edutainment games are games that follow the traditional pedagogical methods for subjects and tend to be in a drill and skill or kill format (Dondlinger, 2007). Edutainment games, along with incorporating a learning objective, tend to heavily rely on visual or narrative game formats. With edutainment games, the main purpose is to promote student learning through interaction, exploration, trial and error and repetition, so much so that that the student gets lost in having fun without realizing they are learning (Green & McNeese, 2007).

Educational games, however, require the use of higher order thinking skills to strategize, to problem-solve and to test hypotheses (Dondlinger, 2007). Educational games, therefore, are "games (that) include a system of rewards and goals which motivate players, a narrative context which situates activity and establishes rules of engagement, learning content that is relevant to the narrative plot, and interactive cues that prompt learning and provide feedback" (Dondlinger, 2007, p. 22). Green and McNeese (2007) further clarify how in an educational game, the end or conclusion should be reached because of knowledge or skill. In addition, edutainment games further differ by containing elements of competition (or cooperation) along with suspense and/or drama (Green & McNeese, 2007).

Although the classifying video games into “educational” and “not educational” is useful, it is not typically how video games, especially commercially available video games, are classified. Instead, video games are classified or grouped by genre or type. There is no widely-accepted taxonomy for game genres or agreement on how to even divide up the genres. As such, the creation of video game genres is still being debated in the literature.

One of the earliest attempts to classify games was by Chris Crawford (2011), a game designer. Crawford (2011) divides games into two major categories: skill and action games, and strategy games. Skill and action games emphasize motor and perceptual skills while strategy games emphasize cognitive effort (Crawford, 2011). When Crawford (2011) wrote the first edition of his book on game design in 1984, skill and action games were the largest and most popular types of games: with real time play, a focus on graphics and sound, and the need for a specialized controller. The primary skill needed for skill and action games are hand-eye coordination and fast reaction times. Crawford (2011) further divides the skill and action category into six subgenres: combat, maze, sports, paddle, race, and miscellaneous. In contrast to skill and action games, strategy games emphasize cognition. Crawford (2011) divides strategy games into six subgenres: adventure, Dungeon & Dragon, war games, games of chance, educational and children's games, and interpersonal games. Between the first edition of his book on game design in 1984 and the revised edition in 2011, Crawford (2011) claims that his categorizations have become obsolete. He asserts that skill and action games have essentially merged with strategy games, with most games having elements of both genres (Crawford, 2011).



McCann (2009) discusses how video games are grouped into genres based on the interaction during the game play, but that there is no standardized criteria to define the different genres. What complicates the classification of video games is that many games are crossovers, in that they contain elements of different genres. One list McCann (2009) examined contained 26 different genres, but that there seems to be nine different genres that are the most accepted:

- Action
- Action-adventure
- Adventure
- Massively Multiplayer Online Role Playing Game (MMORPG)
- Music
- Role-playing
- Simulation
- Sports
- Strategy

In Watson's (2007) review of the literature on video game genres, he finds that while different researchers have different genre lists but finds six genres that are common to all the articles:

- Action
- Adventure
- Fighting/Combat
- Sports
- Strategy
- Role-playing

This list is similar to McCann's (2009) list, but eliminates action-adventure, music and MMORPGS but includes fighting/combat. Prensky (2001) and Kirriemuir and McFarlane (2004) also include puzzle games in their lists of video game genres. Gros (2007) adds simulation to his list of game genres.

Watson (2007) discussed how there are several different ways to categorize video games found in the literature, the most common way to categorize focuses on the differences between the games. These classification systems examine issues of game: format, structure, content and learning goals, among other elements. He proposed that video games should be categorized by learning goals instead (2007). This could potentially solve issues brought up by Kirriemuir and McFarlane (2004) such as video games that cross genres or resist classification.

Nelson and Strachain (2009) suggest a different way to categorize video games based on the skills needed to play the game. Based on their experimental research, they suggest a taxonomy based on the visuo-spatial skills needed. They list eight different skills, such as speed, accuracy, visual search and spatial navigation. Nelson and Strachain (2009) mention there are some possible concerns with this taxonomy, as many games require many of the same skills, so there would need to be some kind of grading system.

Hong, Hwang, Lu, Cheng, Lee, and Lin (2009) examine the classification of educational games, dividing educational games into five different genres:

- Drill and practice
- Single combat
- Stable contest
- Evolutionary contest

- Contextual.

This classification is based on the knowledge required in the game and how the game is played, for example, if it is a turn-based game.

A different taxonomy has been developed by Djaouti, Alvarez, Jessel, and Methel (2007), based on the different rules found in games. Each rule, or fundamental element, makes up a “game brick.” When these “game bricks” are combined into “Metabricks,” it is then possible to classify video games according to what “Metabricks” are necessary for game play. Djaouti et al. (2007) have currently classified over 1000 video games using “game bricks” and “Metabricks.”

Apperly (2006) discusses how current video game genres focus on and classify video games primarily based on representational characteristics, defined as the visual aesthetics found in the game. He argues that video games should be classified by their interactive characteristics instead. Interactivity refers to the actions the video game player must take in order to play the game. By classifying video games by interactivity, it allows researchers the opportunity to look at the similarities between video games, instead of superficial differences (Apperly, 2006).

As can be seen from the literature, there is no clear consensus classifying games by type or genre. The most common classification scheme has two categories: game and simulation, but this simple grouping does not make it easy to compare and contrast different video games. There does seem to be a push to classify games by how they are played or how they are used.

### **Learning Theories Involving Games**

Intuitively, it may seem like a great idea to add specific types of games to an academic or educational setting. However, is the addition of games as a pedagogical

technique or tool supported by any learning theories? Much of the literature suggests that most researchers support the use of games in education through the use of either the theories of learning developed by Piaget or socio-cultural learning theory as developed by Vygotsky.

Hogle (1997) asserts that learning theory developed by Piaget, specifically assimilation and accommodation, supports educational gaming and its cognitive benefits, as games can trigger these cognitive processes. Of the 35 articles that Dondlinger (2007) reviewed, the researchers used one (or more) of three different learning theories: constructivism, constructionism and situated learning, to support the use of video games.

Squire and Jan (2007) discuss how, although theories of game-based learning are just being developed, there is a push to combine socio-cultural approaches to learning with games. While some researchers use pre-existing learning theories, other researchers have determined that current learning theories are insufficient to explain how games, especially digital games, such as video games, influence the learner/player and impact their cognitive processes.

Perhaps the most comprehensive conceptual framework and learning theory to study digital games has been developed by Tennyson & Jorczak (2008), based on the Interactive Cognitive Complexity (ICC) learning model. This is an integrative information processing learning model in which learning is the result of complex, non-linear interactions of different internal and external variables related to the cognitive system of the learner. This framework is primarily used to study simulation-type instructional games, as simulation games have the highest potential for instruction and learning, according to the researchers, and therefore are the most comprehensive and

flexible way to study the characteristics of instructional games. In the ICC model, the cognitive system includes affect, knowledge base and cognitive strategies along with the executive control functions and internal processing components with these variables interacting with each other to increase motivation and learning (Tennyson & Jorczak, 2008). The ICC model is iterative, as information comes in from an external source, it interacts with the current knowledge base and affective states to create new knowledge bases and affective states.

Tennyson & Jorczak (2008) then create five conceptual categories of instruction-relevant game variables:

- Virtual Context
- Problem Specification
- Interaction and Control
- Learning Support
- Social Interaction

In essence, Tennyson & Jorczak (2008) create a conceptual framework in which the framework variables are the variables of the games, which then affect the function and the content of the cognitive system of the player.

The most well known theory used in the development of the conceptual framework for game based learning is the cognitive model of multimedia learning of Moreno and Mayer (2005). Meaningful learning only occurs when learners construct knowledge representations based on existing knowledge and new information. To construct this new representation, the learner must use cognitive processes to determine what to include in the representation and to make it meaningful (Moreno and Mayer,

2005).

Kiili (2007) suggests that current research has separated game design from learning in games and proposes a new theory, problem-based gaming, to rectify this issue. Problem-based gaming (PBG) is based on problem-based learning, which focuses on ill-structured problems; the kinds of problems learners encounter in real-life, which may have no clear solution. In PBG, emphasis is placed on authentic or realistic learning tasks, experiential learning and collaboration, suggesting experiential learning theory as another foundation for PBG. What makes PBG different from other gaming learning theories is the addition of and the emphasis on reflection in the gaming process (Kiili, 2007).

### **Games in Education**

Although it is crucial for games in general, and digital games in particular, to have theoretical underpinnings for their use in educational settings, it is equally important to look at the more practical aspects of integrating games into the average classroom. First, the use of games in education in general is examined. Next, the impact games have on cognitive processes is discussed. The focus then narrows to games in science education and then finally ties together the research involving games being used to impact science reasoning. Although many of the articles deal with nondigital games, such as board games, it is assumed the general findings can be equally applied to digital games.

Games can be used to teach a wide variety of educational objectives from the cognitive, affective and psychomotor domains and are especially good at helping students achieve the higher-order thinking skills of analysis, synthesis and evaluation. A well-designed and properly used game can promote transfer of learning between contexts and

assist in developing creative thinking skills while engaging and motivating students.

Games are often inter-disciplinary or multi-disciplinary, helping students integrate concepts pulled from various academic domains as well more accurately reflecting problems found in the real world and can provide practical experience in the academic setting (Ellington, Addinall, & Percival, 1981).

Gredler (2004) discusses similar benefits to games in education as Ellington et al. (1981) but also adds that games can help students identify missing knowledge and skills as well as help them apply and practice a wide variety of knowledge and skills.

Cruickshank and Tefler (1980) also concur about the advantages of games in education. Some of the advantages of games are that they are attractive, novel, provide a better classroom atmosphere in terms of motivation and management, and help keep the learner focused on the task (Heinich et al., 2002). The primary advantages include increased engagement, interest and fun, greater transfer of knowledge between contexts, and allow students to practice skills in a safe, responsive environment (Cruickshank & Tefler, 1980).

In contrast to Prensky (2001), Heinich et al. (2002) limit the use of computer games to drill and practice and limit the use computer simulations to decision-making processes. Prensky (2001) would argue that computer games and simulations can be used in much wider applications than drill and practice and different game genres can be used in many more ways than initially is apparent.

The primary disadvantage of using games in education is when things, such as secondary goals or competition, overshadow or eclipse the primary learning objectives. The disadvantages are the cost in terms of time and money as well as difficulty

implementing simulations and games into the classroom (Cruickshank & Tefler, 1980; Heinich et al., 2002). Cruickshank and Tefler (1980) argue that the role of games in education is not to replace traditional educational methods but rather to supplement them. However, in some cases, games are more effective than traditional methods, such as learning and practicing problem-solving (Cruickshank & Tefler, 1980).

Jenkins (2002) builds on the previous arguments by including the idea that games can help learners try new intellectual skills and that games can benefit students with learning differences. Additionally, games can help students see the real-world applications of their advanced math and science classes using that knowledge necessary to win (Jenkins, 2002). Finally, games themselves could become an assessment tool if students need to build or design an object.

Just because a game claims to be educational does not mean it is effective in accomplishing specific learning goals or outcomes or even educational. Fisch (2005) rightly points out that just because there is educational content in the game does not mean the game is effective in educational terms, and that the effectiveness of any given game depends on a variety of different factors. One thing that Fisch (2005) notes is that some topics may lend themselves better to computer games than others, for example, some topics may require more tactile experiences than computer games allow. Essentially computerizing drill and skill worksheets and adding some kind of entertaining computer reward is not particularly effective as students will remember the rewards but will not remember the actual educational content. It is important to make the educational content fully integral to the game play and not just an add-on feature. Feedback and hints should help scaffold or support the player and explain in some way what the learner got wrong



so that the player can learn and improve. Additionally, the feedback or hints should become more and more detailed as the student gets more "stuck" in the game (Fisch, 2005).

Perhaps the most interesting aspect of the article by Fisch (2005) is the discussion of how computer games can serve as a launching pad for learning outside the game. The topics and content students introduced in the games can then be reinforced outside the game using different activities, such as reading or discussions. Educational game designers can develop offline activities to make the games more effective educationally, and to increase the likelihood that the games will be used in the first place (Fisch, 2005).

Game playing piques curiosity, develops student creativity, gives players pleasure, and a sense of accomplishment, along with challenging them. When students are having fun, they tend to pay more attention and participate more willingly, which can lead to being more receptive to learning. Games can do more than simply help students develop technology skills but help them develop skills needed for the adult world such as developing ways to apply new knowledge and build relationships between new and old knowledge (Green & McNeese, 2007).

Green and McNeese (2007) argue that many current students have grown up playing video games, thereby changing how they think and even how they learn, similar to the arguments of Prenksy (2001) and Gee (2003). Furthermore, students are most likely not playing edutainment games but rather are playing popular games outside of school. Green and McNeese (2007) assert that current students, especially gamers, because they have spent so much time in a technology rich environment and playing video games, have different cognitive skills and processes than previous generations of

students. To be successful at games, gamers have learned to process large amounts of information simultaneously and quickly, especially information presented visually as games are highly visual. Gamers have also become proficient at multi-tasking and dealing with information that is not presented in a linear fashion. To be successful in a game, players have to find and determine what information is relevant as well as quickly taking stock of new situations (Green & McNeese, 2007). Finally, gamers figure out how to play the game and the rules of the game, through trial and error, observation, and hypothesis testing, skills which are necessary for success in the sciences. The problem with this research and similar research is that there is scant quantitative evidence to support these statements.

One area that is rapidly emerging in the literature discusses the fundamental ways that video gaming may change brain structure and function in order to support the statements of Green and McNeese (2007) among others. Irons, Remington, and McLean (2011) examined the effects of action video games on the attentional capacity of video game players and non-video game players to verify recent claims that video games improve attention. In their experiment, they found that there were no significant differences between the two groups in terms of attentional capacity, concluding that video game playing does not improve attention (Irons et al., 2011).

Although not strictly about video games or educational technology, Nicholas Carr's book *The Shallows*, discusses the implications of the Internet on the way humans think (2011). Carr (2011) examines the evidence and concludes that the Internet is essentially changing how the brain works. The human brain is able to adapt and change depending on the demands placed on it and furthermore, the way people think is

influenced by the tools they use. The brain will build new and stronger connections when new skills are learned or practiced while skills that are not used will weaken (Carr, 2011). A video game is a tool and a problem-solving video game is a tool used to practice problem solving. It makes sense that playing video games would change the structure of the brain and that playing problem-solving video games would strengthen those areas of the brain used for problem solving. Carr (2011) notes that mental capacities developed for one purpose can potentially be used for other things. It would then seem logical that problem-solving skills practiced with a video game could be transferred to other situations; problems with transfer notwithstanding. Carr (2011) discusses how he undertook his research because he was having trouble reading long texts; it is possible in the rush to implement the latest technology, there is little focus on potential negative impacts.

Okan (2003) argues against adopting and implementing educational technology and edutainment software haphazardly into classrooms without significant reflection and research on the possible benefits as well as the potential risks of educational technology. Okan (2003) further argues that educators do a disservice to students by trying to make all learning fun, as it can change the attitudes of students towards learning in negative ways as well as trivializing the learning process. Additionally, edutainment, by making learning fun, may be sending students the wrong message, since learning is something that needs to be worked at and needs effort from the student.

Okan (2003) cautions against educational technology, especially games that are simply special effects. Edutainment should be based on findings from constructivism, educational technology and educational psychology (Okan, 2003). Like Prensky (2001),

Okan (2003) recognizes that edutainment software may be having an impact on what learning is and the way in which students learn. Unlike, Prensky (2001), Okan (2003) does not unconditionally embrace edutainment without serious questions. Green and McNeese (2007) also caution against widely implementing games in education especially when games are implemented without the support of research. Green and McNeese (2007) expand on the arguments of Okan (2003) against edutainment games in education introducing concerns about the games not being culturally neutral and there may be hidden biases embedded within the games. Again, there is concern that these games maybe brought in because they are new technology, using technology for the sake of using technology, without giving any thought to learning outcomes (Green & McNeese, 2007).

### **Studies Pertaining to Games in Education**

There have been a few experimental studies, literature reviews, and meta-analyses on the use of games in education. Many of the literature reviews are critical of the experimental studies pertaining to games because of the methodological problems (such as sample size, rigor and design) as well as not providing enough statistical information for comparative analysis (for example: Van Sickle, 1986). As other researchers (such as Randel et al., 1992) have noted, there is a lack of experimental or quasi-experimental studies involving games in education. The majority of the research focuses on designing games for educations, though there is a trend toward more empirical studies of learning outcomes.

Van Sickle (1986) conducted a review of the research associated with simulation gaming. The most significant issue Van Sickle (1986) found was the lack of information

and the lack of rigor in the research papers, as many papers did not include enough information about design, subjects and teachers. Nearly half of the studies Van Sickle (1986) examined did not have enough statistical information for him to compute effect sizes leaving only 22 studies with sufficient information to quantitatively review. Van Sickle (1986) computed effect sizes and then compared the effect sizes to determine the effectiveness of simulation gaming, reporting that there is evidence that simulation games can produce a small to moderate effect on the cognitive learning of participants when compared to other instructional techniques. The research supports the belief that simulation gaming is not more effective than lecture for short term retention, but that simulation games are more effective than lecture for longer term retention (Van Sickle, 1986). The review of Van Sickle focused on simulation games used in economics and political science; it remains unclear whether similar results would be achieved in a different subject area.

Randel, Morris, Wetzel, and Whitehall (1992) conducted a review of the educational effectiveness of games and simulation games published since 1966 and included seven previous reviews, for a total of 68 studies. They found there was an over-emphasis on descriptive reports and had serious concerns about the method and design of many of the studies. The majority of the articles (56%) found no difference between instruction using games and simulation games and traditional instructional methods, with only a third of the articles supporting games and simulation games over traditional instructional methods (Randel et al., 1992).

Overall, Randel et al. (1992) reports that subjects where the content can be specifically targeted and the learning objectives are clear are more likely to benefit from

using simulation and non-simulation games as the majority of null results were in the area of social studies. Retention and student interest were all found to increase when games and simulation games were used (Randel et al., 1992).

Dondlinger (2007) conducted a review of 35 articles on educational video game design and found that all of the articles reported motivation as a significant characteristic of educational games and that truly effective games contained both intrinsic and extrinsic rewards for playing. Most researchers, according to Dondlinger (2007), found that goals and rules were as important as narrative context in game design and that different levels that contained different goals, helped motivate players to keep playing. According to Dondlinger (2007), the articles presented mixed results with respect to gender and games. Although it is presumed that there is a difference between girls and boys when playing games, there is no clear empirical research that supports the presumption that boys are better gamers (Dondlinger, 2007).

The purpose of a research study conducted by Dempsey, Lucassen, Haynes, and Casey (1996) was to examine the instructional applications of computer games with adults.

For this study, the authors developed five criteria for selecting games:

- The game must be simple to play.
- The game can be adapted and cheaply reprogrammed.
- The game must have an identifiable educational use.
- The game must be different from the other games in its category.
- The game must be playable by one player (Dempsey et al., 1996).

The sample for this study was 40 adults of various ages, evenly divided as to gender and

educational backgrounds with each participant being randomly assigned 4 games to play (Dempsey et al., 1996).

The most relevant result pertains to the strategies players used when attempting the games. Over three-fourths (79%) of the players used trial and error strategies. Trial and error is defined as the absence of a specific strategy when playing and involves reacting to feedback supplied by the game, thereby learning how to play the game. Even if the player knew an effective strategy, they would often try trial and error first, only going back to read instructions or receive guidance if he or she was stuck. When playing puzzle games, players often used visual imagery techniques and tended to read instructions. Another finding was that players often became frustrated if they did not understand the goal of the game. Taking these two findings together, the practical outcome is to allow time for players to use discovery learning when playing games and making sure the goals and instructions of the game are clear (Dempsey et al., 1996).

Lee, Luchini, Michael, Norris, and Soloway (2004) conducted a pilot study to investigate the integration of an educational video game they designed for the Nintendo Game Boy Advance into a second grade class. Teachers were free to implement the games; which focused on drills for addition and subtraction into the regular curriculum in whatever manner they chose, with students playing an average of 10-15 minutes a day for about four weeks. Students completed an average of 2.8 times as many problems as they would have from traditional instruction using worksheets as well as increasing the difficulty of the game, exploring areas of the game that were not explained to them and collaborating with their peers. Perhaps the most surprising result were the reports about the behaviors of students, with teachers reporting an improvement in classroom discipline

and dynamics when the game was used as a reward for good behavior as well as good behavior while using the Game Boys (Lee et al., 2004).

Pulman (2007) examined the use of Brain Training software and Nintendo DS Lites with health science students who had trouble with numeracy. Brain Training software includes such things as rapid calculations, ordering numbers, and keeping track of people entering and leaving in a house. The study was qualitative in nature, with students answering questionnaires about the use of the DS Lite and the Brain Training software. Most students enjoyed using the DS Lites and the software, feeling it helped them with their numeracy skills. One student felt the DS Lites were much easier to use than the Internet tutoring program available. The biggest problems students had involved the writing and voice recognition software and that there were not enough DS Lites available for the participants to use whenever and wherever they wanted (Pulman, 2007).

Amory, Naicker, Vincent and Adams (1999) conducted a short research study to determine which game genre students liked the most and which game genre would be most appropriate for educational applications using 20 first and second year biology students who did not regularly play video games. Students played four different types of games: a strategy game, an adventure game, a simulation and a first-person shooter. The authors found that the adventure and strategy games were favored by the students with students feeling those types of games needed a wider variety of intellectual skills in order to play (Amory et al., 1999). Students did not appear to like the simulation game because they found the interface too confusing and did not receive enough feedback about their progress (Amory et al., 1999). This could also be a function of the time spent playing the game because students may not have played the game long enough to truly understand it



or benefit from it. Armory et al. (1999) concluded that the adventure game genre would be the best foundation for future educational games.

### **Games and Cognitive Processes**

It has been argued that games can teach a variety of content and skills. Can games be used to teach cognitive and metacognitive skills such working backwards and reflection? Hogle (1996) and Pillay (2003), along with others, propose that games could potentially help players improve their cognitive and metacognitive processes and strategies. Pillay (2003) discusses in-depth the cognitive processes used when playing recreational computer games for fun. Some of these processes include anticipatory thinking and thinking backwards, also known as means-ends analysis. Anticipatory thinking involves anticipating and preparing for future situations that could occur in the game. Anticipatory thinking can be considered metacognition, as it involves not only monitoring self thinking but involves extending the information to new situations. The cognitive process of working backward involves identifying subgoals needed to achieve a solution and then working backwards from those subgoals to solve the problem. This is a particularly effective strategy when there is a lack of sufficient knowledge or information. Along with these and other cognitive processes, recreational computer games can help players with time and memory management and effective use of knowledge (Pillay, 2003).

In summarizing the literature, Pillay (2003) believes it is plausible that, by playing games, players develop schema and organized knowledge structures that allow them to use the needed knowledge when prompted with appropriate cues. Additionally, by playing, or developing expertise in recreational computer games, players may have an

easier time automating and transferring the knowledge structures between different environments, especially computer-based environments (Pillay, 2003).

In a mixed methods research study, where the primary research approach was a modified protocol analysis known as PARI (Precursor, Action, Result, Interpretations), Pillay (2003) examined the cognitive processes secondary school students employed when playing a problem-solving and a strategy-adventure recreational computer game. The results suggest that recreational computer games can increase the performance of students on technology-based educational tasks (Pillay, 2003). The results also suggested that the strategy-adventure game was most effective in helping players develop schemas or knowledge structures that they can use in other contexts.

Henderson (2002) examined the video game playing of two 13 year olds, one male and one female, to discover what cognitive processes are used when playing a popular role-playing action/adventure game. Using stimulated recall interviews, Henderson (2002) discovered that the two players used 18 different types of cognitive skills, many of which were higher-order such as evaluating their gameplay. Deduction and induction were also utilized by the players as they played (Henderson, 2002). This study supports the use of video games as an informal education experience to engage and practice cognitive skills and processes.

Alkan and Cagiltay (2007) examined how novices learned to play computer games using eye tracking. The researchers had 15 undergraduates play a puzzle game that was unfamiliar to them and then had them answer questions about their experience. The researchers found that twelve students used a trial and error strategy, with only one student reporting that he used a systematic strategy to solve the puzzles (Alkan &

Cagiltay, 2007). Alkan & Cagiltay (2007) also noted that students did not read the instructions but did follow the instructions given in the hints when accessed. Students reported they needed intelligence, problem-solving skills and reasoning to solve the puzzles in the game and that they preferred more complex action and strategy games (Alkan & Cagiltay, 2007). Based on measuring eye tracking and fixation, Alkan & Cagiltay (2007) conclude that based on what was happening in the game, the cognitive processes of the player changed depending on what was occurring in the game.

### **Games and Science Education**

What does the literature and research say about using games in science education? Ellington, Addinall, & Percival (1981) discuss how games can be used in all levels of science education to teach basic science content and about science and its role in society. Additionally, games can use science content or science-based activities and experiences to develop necessary skills, especially when using a multi-disciplinary approach. In some cases, games can be more effective or offer some advantage, over traditional science teaching methods, depending on the content and the context. Games could also be used to help students develop laboratory skills and provide exposure to a variety of different experiences when actual hands-on practice is not available or practical, for example experiments that take a great deal of time or use hazardous materials (Ellington et al., 1981).

Squire, Barnett, Grant, and Higginbotham (2004) conducted a quantitative-qualitative pilot study with 8th graders to determine the effectiveness of a simulation game designed to teach electrostatics. The researchers used a pre-post test design and conducted interviews before and after the intervention. Overall, the experimental group

that played the Supercharged! game outperformed the control group, with boys outperforming girls. Additionally, during the post interviews, students in the control group relied on what they had memorized, while students in the experimental group recalled their experiences from the game (Squire et al., 2004).

Squire et al. (2004) noted two significant issues with the incorporation of Supercharged! into the classroom. First, there were some implementation issues. Students needed more guidance than was initially provided and were unfamiliar with learning through inquiry. Classroom culture had a significant impact on how the game was accepted and used by the students. Second, many of the students, especially the boys, only wanted to beat the game, and did not want to spend time trying new strategies or reflecting. In contrast, the girls appeared to want to explore and discuss the game. Finally, during the interviews, students had trouble interpreting game events and game vocabulary using electrostatic concepts, especially since the terms were introduced in cut scenes which were skipped by many students (Squire et al., 2004). The authors failed to note whether the difference between the control and the experimental groups was significant, nor did they mention if the difference between pre-test and post-test scores was significant for either group.

### **Games and Science Reasoning**

There has been a great deal of discussion about the use and effectiveness of games. When designed with educational use in mind and when used appropriately in the academic setting, games can be very effective. What research has been conducted using games to improve science reasoning?

Green and McNeese (2007) argue that students playing games practice using a variety of skills, such as strategizing and problem-solving, which can help develop critical thinking skills. Adventure games require logical reasoning while strategy games require analytical skills (Green & McNeese, 2007).

Ellington et al. (1981) assert that science reasoning skills and general critical thinking skills that science educators hope to develop in students can be developed using games that teach through science. In other words, science provides the context for the game and can be used to teach higher-order thinking skills. Hogle (1996) argues that while games may not teach logic or reasoning skills, they do allow players to practice these skills.

Tornkvist (1981) discusses the use of the game Mastermind, a non-digital game, to help physics students develop the science process or inquiry skills needed to conduct experiments. Playing Mastermind helps students learn how to develop and test hypotheses, design experiments keeping such things as control of variables in mind, and how to interpret results. It is critical, after students have played Mastermind, to discuss the problem-solving involved and reflect upon their thinking to ensure that students understand what they are learning or practicing by playing the game and are then able to transfer that learning to other situations and contexts (Tornkvist, 1981).

Wood and Stewart (1987) used a modified, computerized version of the game Mastermind to determine whether a computer game, not originally designed to teach logic or other practical reasoning skills, could indeed be used for that purpose. Mastermind was chosen because it is relatively easy to learn how to play, it provides immediate feedback, it incorporates both inductive and deductive reasoning and since

Mastermind does not depend on a specific context, any reasoning skills developed could theoretically be transferred to other contexts. (Wood & Stewart, 1987). Reasoning was assessed using the Watson-Glaser Critical Thinking Appraisal (Wood & Stewart, 1987). Using a randomized pre-post test design, Wood and Stewart (1987) had undergraduate students play the computerized version of Mastermind, for intervals ranging from two to six hours, depending on how long it took the student to master the game. Wood and Stewart (1987) found that errors of logic and hedging decreased for the experimental group, while there was no significant change between the control and experimental group for risk, reading and opinion errors.

Stadler (1998) describes using Black Box, a board game, to teach scientific reasoning, specifically inductive and deductive reasoning. As the students play the game, they use inductive and deductive reasoning to generate hypotheses, similar to how scientists do science, in order to win the game (Stadler, 1998). Anecdotal evidence provided by Stadler (1998) suggests that the game may have some kind of an effect, but what that effect could be was unclear.

Hatcher (1990) discusses a method of using riddles to help students understand the scientific thinking and the process of science. He lists seven lessons or aspects of scientific thinking that can be taught using riddles:

1. It is often important to view a problem from more than one perspective, also known as lateral thinking.
2. Prior assumptions concerning data are dangerous.
3. Yes/no questions, properly formed, yield highly useful data. (Relates to the concept of null and alternative hypotheses.)

4. Details that do not fit expected patterns are often of crucial importance.
5. Persistence is a key quality in problem solving.
6. By expecting complicated answers, simple ones may be overlooked.
7. Science is an enterprise that is frustrating, exciting and requires considerable courage (p. 123-124).

### **Games and Spatial Reasoning**

Games also teach the player about spatial relationships, which can be as simple as reading a map to mapping social relationships. Spatial relationships also influence the concept of humans having the ability to make and use tools. In games, this tool making and usage can be very concrete, such as putting an object together or it can be very abstract, involving the relationships between objects. Most good games incorporate some aspect of spatial reasoning, such as classifying and collating as well as exercising power over a space (Koster, 2005).

### **Game Studies**

Kiili (2007) conducted group interviews of 12 students out of a pool of 92 students who played a computerized business simulation game for roughly five hours. The results of the interviews suggested that students believed the simulation game allowed them to apply knowledge in authentic contexts rather than helping them learn new knowledge. The simulation game also helped learners see the whole picture, instead of discrete pieces (Kiili, 2007).

Like similar studies, Kiili (2007) found that most students employed a trial and error strategy. In the interviews, it was discovered the simulation game ran too fast to allow sufficient time to develop and try different strategies. Additionally, the pace of the

simulation game prevented the students from being able to adequately reflect upon what they were doing and possible alternative strategies (Kiili, 2007). He concludes that the use of PBG is supported as students formed and tested strategies.

### **Teaching with Games**

Up until this point in the literature review, the focus has been on the perspective of the student. What does the research say about the perspective of the teacher on games in education and science education?

Sandford, Ulicsak, Facer, and Rudd (2007) conducted a survey of English and Welsh students and teachers and performed a case study of how twelve teachers used computer games in a formal classroom setting. For the surveys, 924 primary and secondary school teachers answered questions about computer games in the classroom and 2334 secondary school students answered questions about games in and out of the classroom. What they found was that a slight majority (59%) of teachers were willing to use computer games in the classroom while slightly less than 2/3 of students would like computer games in the classroom. Slightly more than a third of teachers (37%) would not consider using computer games, while 22% of students felt that computer games should not be used. There was also a difference in what kinds of skills teachers and students thought they could learn from computer games. Teachers felt that computer games would help students with subject knowledge and increase motivation, while students felt that the games would help them with social skills. Both students and teachers thought that playing computer games increased general problem-solving skills. For the case studies, three games in which the players had total control over the environment were used (Sandford et al., 2007). The games were *Knights of Honor*, *The Sims 2* and *RollerCoaster Tycoon 3*



and various learning activities were designed around these games. For example, *RollerCoaster Tycoon 3* was used to help students learn about forces and energy (Sandford et al., 2007).

The researchers found that the expectations and assumptions of teachers did not match reality (Sandford et al., 2007). First, the teachers expected all of the students to be motivated by the games, which was not the case (Sandford et al., 2007). Second, teachers also thought that the students would quickly learn how to play the games or would already be competent, which lead to problems when the activities took far longer than planned (Sandford et al., 2007). Perhaps the most surprising observation was that the games were most effective when teachers had a clear understanding of the content the games were trying to cover; in other words, the impact depended less on technological pedagogical content knowledge and content knowledge and more on pedagogical skills (Sandford et al., 2007).

### **Evaluating Games**

Once a decision has been made to use games in an educational setting, how does one determine which games to use for a particular situation and how does one evaluate whether a particular game was effective in meeting the necessary educational objectives? It is important to remember that each game must be evaluated for each educational context, as not all games or types of games are compatible with all contexts and situations.

Ellington et al. (1981) discussed how this evaluation is often lacking and that often a game is considered successful if it works based on anecdotal evidence rather than using rigorous methods such as cognitive and noncognitive tests and self-reports. Hogle

(1996) also discusses the challenges in assessing the benefits of educational games, especially when the benefits may not be directly measurable. Hogle (1996) asserts that since games are cognitive tools, they must be evaluated according to how well they foster abilities and stimulate activities within the appropriate context, especially when looking at how learner differences impact the effectiveness of a game.

Hogle (1996) points out there are a variety of issues with studies evaluating the effectiveness of educational games. Some of these issues include inappropriate measurement instruments, short-time interval between the pre and post-test and bias occurring from evaluating the game developed by the researchers doing the research (Hogle, 1996). The most difficult problem in assessing educational games as cognitive tools is that these games may foster the implicit learning which happens when a learner learns something without intending to learn it or without realizing that learning is occurring (Hogle, 1996). The problem with implicit learning is that it can be extremely difficult to determine what the learner actually learned and it may be difficult for the learner to verbalize the learning (Hogle, 1996).

When analyzing games for educational use, it is important to keep two concepts in mind: surface structure and deep structure. Surface structure refers to the observable features of a game, such as graphics or sound, while deep structure refers to the underlying psychological mechanisms in the game. Additionally, deep structure is reflected in the interactions between games and simulations and the player (Gredler, 2004).

Rice (2007) developed an evaluation rubric, the Video Game Higher Order Thinking Evaluation Rubric, for teachers to use with commercially available video

games. The rubric consists of twenty yes or no questions which highlight characteristics of video games that make them more effective at teaching higher order thinking skills (Rice, 2007). Sample characteristics included a complex storyline that interests players as well as including complex puzzles requiring effort to solve (Rice, 2007). Based on his review of the literature, Rice (2007) concludes that games with a complex storyline, not just drill and skill, and with complex puzzles to solve, will require higher-order thinking skills to play. Out of a possible score of twenty, Rice (2007) claims that a video game that scores 15 or more is likely to encourage higher order thinking.

### **Summary**

Science reasoning is a crucial skill for science students and for scientific understanding on a larger scale. Science reasoning skills include proportional reasoning, analogical reasoning, hypothetical-deductive reasoning, as well as spatial reasoning. However, some research indicates that it is not a simple task to increase the science reasoning skills of students. Many methods have had mixed results with little indication of long-term gains and transfer of comprehension to or from other areas. There has been more success in improving spatial reasoning skills, which could help to increase science reasoning overall. One possible method to increase science reasoning skills is to have students play games that require science reasoning skills in order to win the game. The literature is teeming with studies discussing whether or not games are viable education tools and what, if any, elements educational games should include. On the other hand, there is a lack of research about the role of games in improving general thinking or reasoning skills, although there are some examples of simulations, games and simulation games being designed and used to teach subject specific content. However, many of these

studies lack statistical rigor and are not rigorously designed. As a result, there is a gap in the literature regarding using commercially available, portable game systems and games to improve science reasoning skills. Research is needed to fill this gap, providing the information to assess whether and how commercial game systems might influence the science reasoning skills of college students.

### **CHAPTER 3: METHODOLOGY**

In order to explore science reasoning skills and behaviors of college students while engaged in playing problem-solving video games, a qualitative research methodology, the case study, was employed with some aspects of quantitative methodology. The case study was chosen to provide a deeper examination of college students' science reasoning than would be possible using more quantitative methods. A description of the specific context, participants, instrumentation, and procedures of the study follows.

#### **Site**

The research study took place at a large, public Mid-Western university located in a large metropolitan region from September 2010 to April 2011. The university is primarily considered a commuter school, although there are an increasing number of students living on-campus. Nearly all of the students (85.7%) come from the surrounding region. According to the website of the university, nearly two-thirds of the students are female with slightly more than three-fourths of students identifying as Caucasian. The average age of undergraduates is 25.9 years of age, while the average age of first-time freshmen is 18.6 years of age.

#### **Recruitment**

Participants for the study were recruited from the university's College of Education. Different classes, focusing on science and math methods courses for pre-service teachers, were visited to describe the study and recruit students. Flyers announcing the study were placed in various locations, such as the library, around the campus of the college of education.

### **Selection of Participants**

Students interested in participating in the research study were directed to a website for further information about the study, including statements about confidentiality and their rights to terminate their participation in the study at any time without consequences, as well as a survey about their video game playing experiences. This survey can be found in Appendix A.

A total of 33 students completed the Video Game Experience Survey (VGES) during September and early October 2010. Criteria for initial selection included interest in participating in the study and whether or not the particular student had prior experience with the video games used in the study. Based on the answers supplied 18 students were invited to take the first science reasoning assessment, Science Reasoning Assessment (SRA) #1. Sample questions are provided in Appendix B. When potential participants indicated they had played one of the three video games used in the study, they were questioned further via email as to how much experience they had playing the specific game. Given the wide variety of puzzles and game play involved, potential participants responding that they had only played one or two puzzles or for less than five minutes were considered to have not played enough to significantly impact the results. Finally, because the research study focused on science reasoning skills, the decision was made that science undergraduate students would be given priority to participate in the study.

The next step in the selection of participants was to score the first science reasoning assessment and determine what scores would be used to select participants. It was determined it would be most interesting and of most benefit to choose participants who were of middle ability with respect to science reasoning skills. Scores on the initial

science reasoning assessment fell between 8 and 22. Students with scores between 13 and 16 (52-64%) on the initial science reasoning assessment were then invited to participate in the full research study. Six students satisfied all the criteria for the full research study and were contacted via email to be invited to participate and attend an initial meeting. One student was unable to be contacted, shrinking the sample size to five. Another participant was going to be invited to participate, but one of the game systems became damaged and a replacement was unable to be procured in time for the study. One student dropped out of the study after the first session.

Only one science major filled out the video game experience survey. This participant then proceeded to take the first reasoning assessment where he scored a 23 (92%). Although he did not meet the study requirements, he was invited to participate, as he would provide a good contrast of how an expert science reasoner approached a novel video game to those who were more inexperienced with science reasoning skills.

### **Participants**

Six students participated in the research study and have been given pseudonyms to protect their anonymity. A brief description and introduction of each participant follows to help provide context for the study. Tables 3.1 and 3.2 summarize the results of the Video Game Experience Survey (VGES) for the sample.

#### **Ryu.**

Ryu is a 22 year old male undergraduate currently pursuing a bachelor of science in physics with an emphasis in astrophysics; he plans to attend graduate school. Currently, he is an undergraduate research assistant in the physics department working on a research project in astrophysics. Ryu considers himself an expert game player or

gamer, primarily playing racing and first person shooter type games and often wears T-shirts with game logos and characters on them. Whenever Ryu has spare time, he plays

Table 3.1

*Demographic Summary of Participants*

Name	Age	Gender	Major	Year	GPA
Ryu	22	Male	Physics	Junior	2.429
Kairi	25	Female	Elementary Education	Senior	3.725
Sora	20	Male	Secondary Education – English	Junior	3.444
Peach	21	Female	Elementary Education	Senior	3.233
Lilo	21	Female	Elementary Education	Senior	3.792

Table 3.2

*Results of Video Game Experience Survey for Sample*

Participant	Length of Time Playing Video Games	Frequency of Play	Self-Rating of Video Game Skill	Number of College Level Math Course	Number of College Level Science Courses	Top Three Favorite Types of Games
Peach	1-2 yrs	Monthly	Not very skilled	5	3	RPG <sup>a</sup> , Sports, Lego
Sora	10+ yrs	Every 2 weeks	Moderately good	1	3	Educational, Brain Training, Puzzle
Kairi	10+ yrs	Daily	Very good	3	3	Brain Training, Puzzle, Problem-solving
Lilo	1-2 yrs	Once every couple months	Average	4	2	FPS <sup>b</sup> , RPG, Sports
Ryu	10+ yrs	daily	Very good	6	10+	FPS, MMORPG <sup>c</sup> , Racing

*Note.* <sup>a</sup>RPG = Role Playing Game <sup>b</sup>FPS = First Person Shooter <sup>c</sup>MMORPG: Massively Multiplayer Online Role Playing Game



video games and carries his Nintendo DSi around all the time and owns multiple game systems. Conversations with Ryu often involve video games. On a test of science reasoning, Ryu scored 92% while other students in the initial sample scored between 48-73%, making him an expert science reasoner in the context of this project.

When not talking about video games, Ryu is often discussing physics and astronomy or other general science topics. For this study, Ryu is functioning as a comparison with and a contrast to novice gamers and novice reasoners.

### **Kairi.**

Kairi, 25, is in her final year as an elementary education major who hopes to teach third grade and will be student teaching in China. She is self-described as a more experienced video game player but reported being reluctant to play the type of games used in the study, preferring more action orientated games. However, she later reported becoming addicted to the games and unable to stop playing. Kairi's score on the initial reasoning assessment was 15 (60%). Due to an oversight, Kairi played the United Kingdom version of the first game, which was essentially the same, except for five puzzles.

### **Sora.**

Sora, 20, is a junior secondary education major with a concentration in English and is a junior. He currently works in construction. Sora appears shy and tends to speak softly when playing. Sora self identifies as somewhere between an expert and novice game player. He plays multiple genres of games, but avoids real time strategy and sports games. Sora had the lowest score, 13 (52%), in the sample for the initial reasoning assessment.

**Peach.**

Peach is a 21 year old elementary education major in her final year. During the second part of the research study, Peach was student teaching. She only plays, but mostly watches, video games with her boyfriend, who prefers first-person shooters. Peach is considered a novice game player and scored 14 (56%) on the reasoning assessment. Peach is rather quiet, especially during game playing sessions, and seems content to let the game lead her through play.

**Lilo.**

Lilo, 21, is an elementary education major, student teaching fifth grade in Spring 2011 and working as a retail clerk, while attending school. Lilo was very talkative and outgoing throughout the study. Although she initially identified herself as an expert gamer on the video game experience survey, as the study continued, she retracted or qualified her expert experience, indicating that she did not play much and did not identify herself as a gamer. She also mentioned that when playing with others, such as her brother, she primarily watched or had the controller taken away. On the initial reasoning assessment, Lilo scored 16 (64%), the highest score in the sample, with the exception of Ryu.

**Instruments**

A variety of instruments were used to collect data for the research case study to examine the effect problem-solving video games might have on the science reasoning skills of college students.

### **Video Game Experience Survey (VGES).**

As part of the selection process, potential participants were asked to fill out a modified, online version of a survey developed by Terlecki and Newcombe (2005) about their video game playing experience. The survey asked questions about what kinds of games the students like to play and how long they played games and was modified to include questions about the video game being used in the study. The survey can be found in Appendix A.

### **Science reasoning assessment.**

To measure the science reasoning of participants, an assessment was needed that did not depend on content knowledge and focused more on logic and hypothetical-deductive and other types of reasoning. The assessment also had to be easily administered and accessible to the researcher. In other words, the assessment did not require special training to be administered and was low-cost or free. Furthermore, it was critical that the questions on the assessment resembled some of the types of puzzles in the video games. The Analytical section on the General Graduate Record Exam (GRE) was chosen as the science reasoning assessment. It was determined to be appropriate given that the potential subjects would be upper level undergraduates. From 1977 to 2002, with a major revision in 1981, the GRE General included two sections of analytical reasoning that consisted of 25 questions each. The KR-20 reliability for the analytical section is .86 (Cohn & Jaeger, 1985). According to Chalifour and Powers (1988), the analytical section has a higher correlation with the quantitative (mathematics) section rather than the verbal section. The analytical section consists of two types of questions, analytical and logical reasoning, and strongly depends on hypothetical-deductive reasoning. The analytical

questions assess the ability to understand relationships between different things, to determine new information from the conditions given and to evaluate information about the observed relationships (Cohn & Jaeger, 1985). These questions are similar to the logic puzzles in the two video games used. The logical reasoning items focus more on the ability to understand, analyze and evaluate arguments (Cohn & Jaeger, 1985).

Four sections from two different administrations of the GRE in 1987 were used. Each section was considered a separate reasoning assessment. The subjects took the reasoning assessments four times at specific points during the study. Sample questions are in Appendix B.

### **Spatial reasoning assessment**

To assess spatial reasoning, participants were given the Purdue Spatial Visualization Test (PSVT). PSVT is a multiple-choice, paper-based test appropriate for students 13 and older. The PSVT was developed by Guay in 1977 and consists of 3 sections of 12 questions each. The first section, Developments, measures how well the student can visualize a flat object folded into a 3-D shape. The second section, Rotations, measures how well a student can visualize the rotation of a 3-D object. Views, the third section, measures how well a student can visualize a 3-D object from another view or perspective. The PSVT was chosen because of ease of administration, its availability and its use in other studies. Psychometric data for the PSVT is lacking. Sample questions from each of the sections on the PSVT can be found in Appendix C.

### **Game system.**

Several factors must be considered when selecting a console for gaming. Based on the discussion in Pulman (2007) it is best that college students are able to take the

game console with them, so that they may play whenever they have a free moment. This narrows the choices of game platforms to iPod/iPhones, other smart phones, Nintendo DSi or DS Lite, or the Sony Playstation Portable (PSP). Because of the different requirements and cost, iPhones, iPods and other smart phones were not considered as possible gaming platforms. Also, games found on one phone platform may not be available on another phone platform. Based on cost and availability of games appropriate for the research study, the Nintendo DS Lite, was selected. The Nintendo DS Lite features dual screens, one of which is a touch screen and enables players to connect to other Nintendo DSs and Wi-Fi networks. It also has a large selection of games in different genres. Figure 1 shows a typical DS.



*Figure 3.1.* A Nintendo DS

### **Games.**

A large portion of the research concerning games in education focused on how to design games for education and what features should or should not be included in a game for academic use. Gredler (2004) discusses five design criteria that are crucial for

effective educational games or games repurposed for education. These five criteria include:

1. Winning should be based on skills or knowledge, rather than luck or chance.
2. The game should address important content rather than trivial details.
3. The game should be easy enough to learn to play but complex enough to keep the player interested in playing.
4. Players should not be “punished” for wrong answers.
5. Games used in education should not be zero-sum exercises and should allow all players the chance to learn (Gredler, 2004).

The two games chosen for this research study were selected because they incorporate elements of good educational game design and are readily available. The two games, *Professor Layton and the Curious Village* and *Professor Layton and the Diabolical Box*, require analogical, proportional and hypothetical-deductive reasoning as well as spatial reasoning, which are major components of science reasoning.

***Professor Layton and the Curious Village.***

*Professor Layton and the Curious Village* (PLCV) is a puzzle adventure game released in 2008 and developed by Level 5 and Nintendo. *Professor Layton and the Curious Village* is a single-player game in which the player takes on the role of either Professor Layton or Luke, the game’s two primary characters, attempting to solve a variety of puzzles in the hopes of locating the golden apple. There are multiple mysteries to solve and different villagers to talk with to obtain needed information. There are 120 puzzles in the game plus bonus puzzles for putting together a painting. Different puzzle

types include sliding blocks, mazes and logic puzzles. Appendix D provides a list of the puzzles played during the think-aloud protocols and includes puzzle number, a screen shot of the puzzle and the puzzle's classification. It is not necessary to complete every puzzle in the game to finish it; however, there are some puzzles that are required before the player is able to move forward. Figure 2 shows a screenshot of a puzzle, of a general game screen and an image of Professor Layton and Luke.



Figure 3.2. Images from Professor Layton and the Curious Village

This game was chosen because of its emphasis on problem-solving and because it demonstrates principles of good game design as discussed in Prensky (2001).

### ***Professor Layton and the Diabolical Box.***

A sequel to *Professor Layton and the Curious Village*, titled *Professor Layton and the Diabolical Box* (PLDB), was released in August 2009. Similar in game play to PLCV, PLDB has the player take on the role of Professor Layton or Luke as they try to

figure out the mystery behind a box that kills anyone who opens it. Players solve upwards of 150 puzzles that include various types of reasoning such as hypothetical-deductive reasoning. Figure 3 shows a screenshot of a puzzle and a general game screen.



Figure 3.3. Professor Layton and the Diabolical Box

Appendix E provides a list of the puzzles played during the think-aloud protocols and includes puzzle number, a screen shot of the puzzle and the puzzle's classification.

*Professor Layton and the Curious Village* and *Professor Layton and the Diabolical Box* incorporate six principles of good game design as discussed by Prensky (2001). First, Professor Layton has rules. There are rules for how to solve the puzzles, for how to move around in the game, and for the order in which the puzzles must be solved. Second, Professor Layton sets goals and objectives for the player. The overall goal of both games is to solve a mystery by correctly completing a variety of puzzles that systematically leads the player closer to the solution. The game provides feedback in a variety of ways. If a player gets a puzzle correct, Professor Layton or Luke gives positive reinforcement and a reward, such as a piece of the robot dog that can be used to “sniff out” coins. If a player gets a puzzle incorrect, Professor Layton or Luke tells the player it is incorrect and gives suggestions to help the player solve the puzzle. If a player is still



stuck, it is possible to “buy” further “hints” with coins that are hidden throughout the game environment. Each puzzle has three hints, which get more and more detailed. Additionally, cheats and walk-throughs are available online if a player becomes stuck.

The puzzles in both PLCV and PLDB provide the player with multiple levels of challenge. For some players, one type of puzzle might be challenging, with another type being relatively simple, thereby providing different levels of challenges. Some of the later puzzles are similar to earlier solved puzzles, allowing the player to use analogous reasoning to solve the new puzzle.

The fifth principle of good game design is interaction. In both games, the player takes on the role of Luke or Professor Layton and can interact with other villagers. Finally, PCLV and PLDB are built around stories. The challenges players must solve are not specific to the story and could be presented as just a series of puzzles. However to help engage the players and to keep them involved, the challenges were embedded into an actual story. Based on the principles of good digital-based learning proposed by Prensky (2001), both PLCV and PLDB are good choice to help students develop their science reasoning through practice with many different types of puzzles.

Finally, Metacritic

(<http://www.metacritic.com/games/platforms/ds/professorlayton>) gives positive reviews of both Professor Layton games from game critics and from game users. The game series seems to be liked and enjoyed by a wide audience of players, which is important when using a game in an educational setting, given the diversity of students.

### **Interview questions.**

After each game playing session, participants were interviewed about their game play. Participants were asked what they liked and disliked about playing, if they felt they had learned anything and were asked to reflect on the thinking process or processes they used during game play. If something different or interesting occurred during game play, such as a participant being unable to solve a puzzle or saying something interesting that needed to be explained, that was also discussed in the interview. For instance, Ryu was stuck on a problem and mentioned using “mathematician’s logic” as the reason he was having trouble. During the interview he was asked to explain what he meant. Participants were also asked to compare the different games as they completed them. Appendix F lists the interview questions for the sessions.

### **Video game play logs.**

Except for Ryu, participants played the majority of each game on their own. To keep track of the progress of the participants and to encourage reflective thinking, participants were asked to fill out an online video game play log. The log asked participants where they were in the game and what they learned. One participant, Lilo, asked for hard copies of the video game play logs. These were later entered into the online form by the researcher. The questions asked in the video game play log can be found in Appendix G.

### **Data Collection**

In order to establish validity and reliability of the proposed study, a variety of different data collection techniques were employed.

**Assessments.**

Participants in the study took the assessments, the Science Reasoning Assessment and the PSVT, multiple times at various times during the game play. Participants completed the Science Reasoning Assessment at the end of every game they completed plus at the beginning of the study for a total of four different scores.

Participants completed the PSVT a total of three times. The first time was at the beginning of the study, at roughly halfway through PLDB, and again at end of the study. Fewer administrations of the PSVT were given because there was only one form of the test available and it was deemed prudent to stretch out the times between administrations to lessen the effects of practice.

**Video game logs.**

The second method of data collection involved participants keeping a record as they played. The participants were asked to write about the thinking strategies they used, if they had any help in solving the puzzles and what, if anything, they thought they learned. These logs were online for the convenience of the participants. Participants were also encouraged to reflect on how the game and the puzzles in the game could help them in other contexts. The majority of research (for example: Kiili, 2007) points to reflection being an important aspect of learning when using digital games in an educational context; because the selected games do not have reflection built in, the reflection must occur outside the game environment. Unfortunately, participants were not consistent in filling out the game logs and as the study continued, participants became less and less consistent in filling the logs as the study progressed.

**Information from the games.**

Each time the participant was involved in a recorded game playing session, information from the games was collected. For the two Professor Layton games, the time spent playing, puzzles found, puzzles solved, hint coins, and total score were recorded. Additionally, from the digital recordings, the time it took participants to solve a particular puzzle was also recorded.

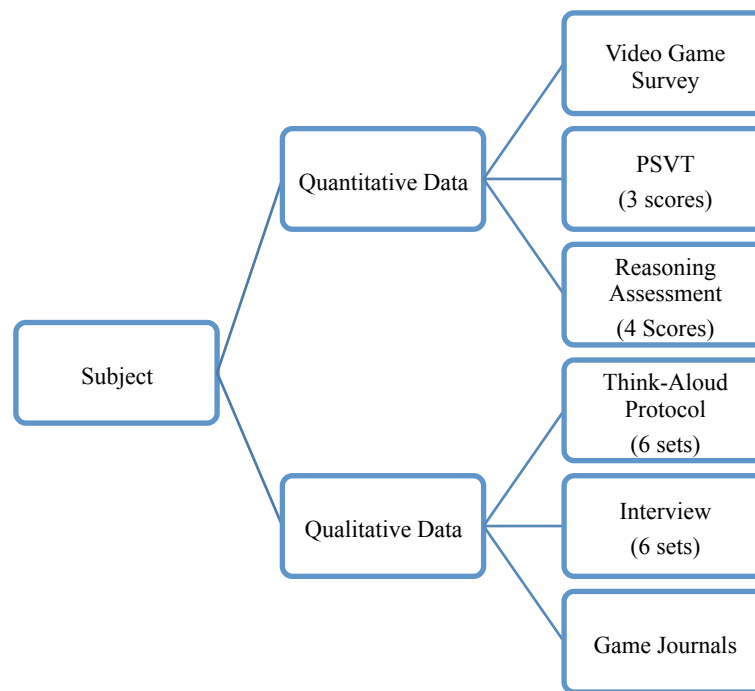
**Interviews.**

After each recorded video game playing session, a short (~15 minutes and ~8 questions) semi-structured interview occurred. If the participant was short on time, the interview questions were emailed. Participants were asked to discuss their game play, what they learned from playing, and if they could apply what they learned to other areas, such as classes. Participants were asked to describe times when they were “stuck” on a puzzle and how they got unstuck as well as any clarifying moments, or “aha!” moments they may have had while playing.

**Think-aloud protocols.**

The primary method of data collection used think-aloud protocols to investigate the cognitive processes of participants as they played the problem-solving video games. Think-aloud protocols were developed by Ericsson and Simon (1980) as a way to analyze the mental processes of a participant engaged in a cognitive task. Think-aloud protocols are unstructured, verbalized reports of problem-solving actions and behaviors (van Someren, Barnard, & Sandberg, 1994). As the players play the video game, they verbalized their thought processes, describing what they were currently thinking and why. The researcher did not prompt or question the player in this protocol, except to

remind the players to verbalize their thinking. As discussed by Ericsson and Simon (1993), the thought process of the participant was not interrupted during a think-aloud protocol, allowing for a more direct view of the cognitive process of the participant. Field notes were taken during the think-aloud protocol to assist with data analysis. Each think-aloud protocol session was digitally recorded and lasted the time it took the participant to solve five puzzles, about 35 to 45 minutes. Figure 3.4 summarizes the data collected for each participant.



*Figure 3.4. Data Collected for Each Subject*

### **Procedure**

Table 3.3 gives an overview of the study procedure. Once a potential participant was identified through the Video Game Experience Survey, he or she was invited to complete the first Reasoning Assessment found online. Based on the scores, a sample of six participants was chosen and contacted via email, inviting them to participate further. Five agreed to participate in the research study. An additional subject who scored high

*Table 3.3. Phases of Study*

Phase	Time	Process
1	Beginning	Recruitment and selection of students for study. Potential students took the Video Game Experience Survey and selected based on their answers.
2	Start of Research	1 <sup>st</sup> Meeting <ul style="list-style-type: none"> <li>• Study was described to student and consent forms were signed.</li> <li>• Student took the SRA and PSVT.</li> <li>• A practice think-aloud protocol was practiced with the student.</li> <li>• Student was given PLCV and began to play the game, while undergoing the think-aloud protocol.</li> <li>• A brief interview was conducted</li> </ul>
	Half-way through PLCV	2 <sup>nd</sup> Meeting <ul style="list-style-type: none"> <li>• Student played PLCV while undergoing the think-aloud protocol.</li> <li>• A brief interview was conducted.</li> </ul>
3	At the end of PLCV	3 <sup>rd</sup> Meeting <ul style="list-style-type: none"> <li>• Student retakes SRA.</li> <li>• Think aloud protocol while finishing PLCV.</li> <li>• Student started playing PLDB for the think-aloud protocol.</li> <li>• A brief interview will be conducted.</li> </ul>
4	Half-way through PLDB	4 <sup>th</sup> Meeting <ul style="list-style-type: none"> <li>• Student retakes PSVT.</li> <li>• Student played PLDB while undergoing the think-aloud protocol.</li> <li>• A brief interview was conducted.</li> </ul>
	At the end of PLDB	5 <sup>th</sup> Meeting <ul style="list-style-type: none"> <li>• Student will retake SRA.</li> <li>• Think aloud protocol while finishing PLDB.</li> <li>• Student started playing adventure game for think-aloud protocol.</li> <li>• A brief interview was conducted.</li> </ul>
5	At the end of adventure game	6 <sup>th</sup> Meeting <ul style="list-style-type: none"> <li>• Student will retake SRA and PSVT.</li> <li>• Think aloud protocol while finishing adventure game.</li> <li>• A brief interview was conducted.</li> </ul>
6	End	Think-aloud protocols and interviews will be transcribed and analyzed. Assessments will be scored. Journals and game records will be analyzed.

in the reasoning assessment was invited to participate as well, as he was the only science student to complete the VGES. At the first meeting, the researcher went over the study protocol with the subject and the consent forms. A short practice of how to do a think-aloud protocol was also conducted. The participant then played the first five puzzles of PLCV and then participated in an interview about their game playing. Finally, the PSVT was taken by the participant. The researcher then reminded the subjects of the next step.

The video game logs, found online, were checked weekly by the researcher to monitor the subjects' progress. If a video game log had not been filled out for that week, the participant was emailed to inquire about progress. This continued throughout the study. When the participants were mid-way through PLCV (Chapter 4; after Puzzle 45), a second video game playing session was conducted. During this second session, the participant played five puzzles while thinking aloud. After the game play, an interview was conducted.

When a subject reached Chapter 7, or around Puzzle 120, the third think-aloud/interview session was conducted. At this session, participants played three to five PLCV puzzles, depending on where they were at the start of the session. They were then asked about their experiences with the entire PLCV game. PLDB was then started by the participant, who proceeded to play three to five of the initial puzzles, and was followed by an interview. Participants were then asked to take Science Reasoning Assessment #2 as soon as possible. All of the participants took the assessment within 10 days of completing PLCV.

Midway through PLDB, at Chapter 3 or around Puzzle 58, participants came in again to engage in a think-aloud protocol/interview session. At this session, participants also took the PSVT for the second time.

The next think-aloud protocol/interview session took place at the end of PLDB, around Chapter 7 and Puzzle 130. Participants played five puzzles and were then interviewed. Participants were then asked to complete Science Reasoning Assessment #3 and all of the participants completed the assessment within 10 days.

When the participants were midway through a third game, a popular adventure role-playing game in which the player takes on the role of the main character, completing a series of tasks and challenges, they came in for the final think-aloud protocol/interview session. At this session, participants took the final PSVT and were asked to complete Science Reasoning Assessment #4 and all participants completed the final assessment within a week. Figure 3.5 summarizes the procedure.

## **Data Analysis**

### **Quantitative.**

Because of the small sample size of both the initial sample that filled out the VGES and the sample used for the full study, only descriptive statistics were appropriate for analysis. The data for the VGES was simply sorted, categorized and counted. For the sample for the full study, descriptive statistics (mean and median) were found for various different measures such as test scores or time taken to solve a puzzle. Test data was graphed to aid in the analysis.



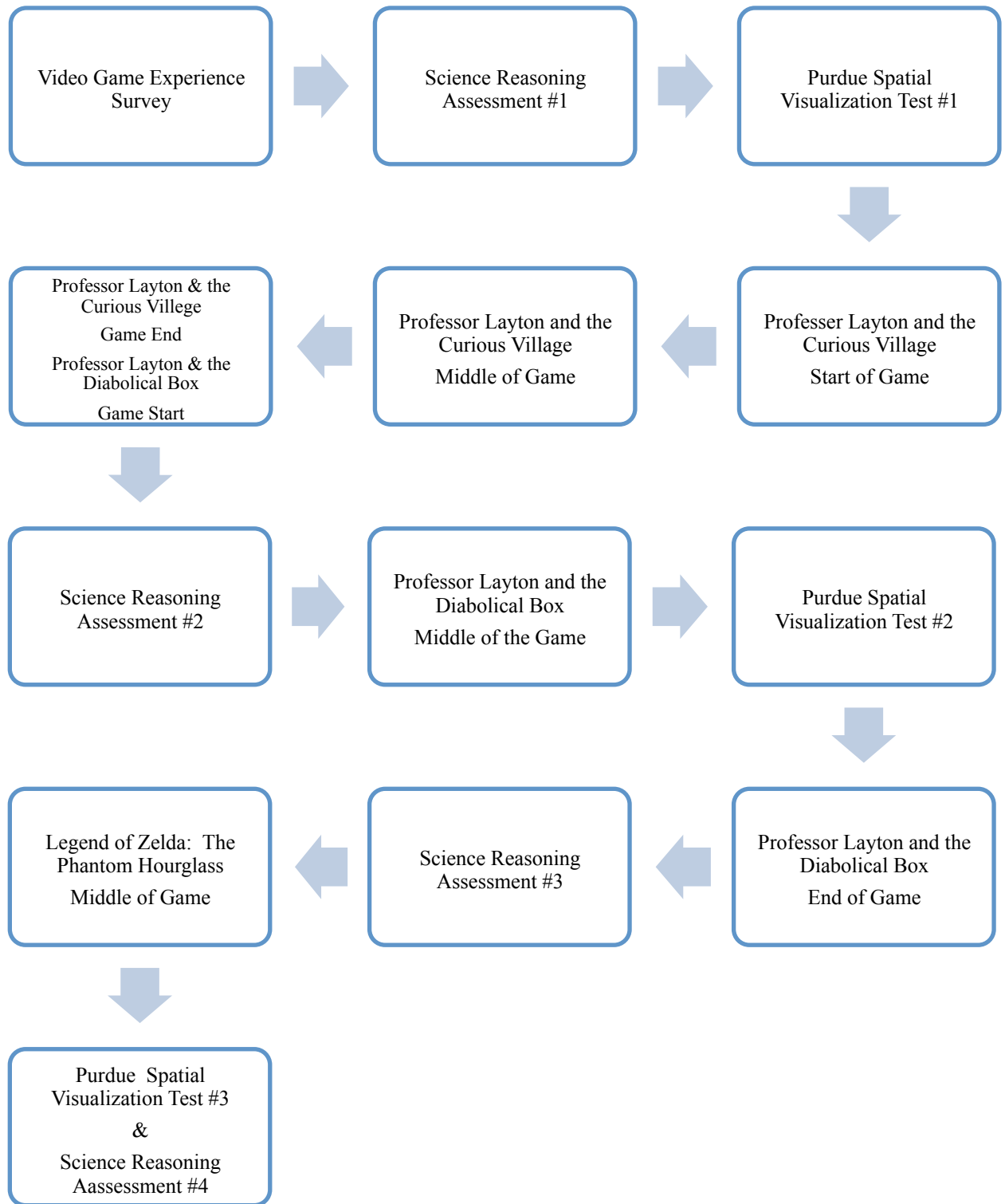


Figure 3.5. Sequence of Events for a Participant

## Qualitative.

### *Transcription.*

For each participant, the researcher transcribed the game playing sessions and the following interviews. The transcripts were formatted as five column tables, as shown in Table 3.4, as an example. Each row of the table is one idea or thought expressed by a participant. If a thought or idea had a pause that was longer than five seconds, the thought was then broken up and put in a separate row.

Transcription was first completed using the digital video recording. All of the time codes in the transcripts were taken from digital video recording. When there was confusion over the participant's speech, <inaud> was recorded. The next step was to use the digital audio recording to verify the transcription from the digital video recording and to clarify the participant's speech

*Table 3.4.*

### Transcript Example

Puzzle	Time	Ryu	Researcher	Notes
	4:25	Luke's going to get the violin. He needs some music in his life.		In response to game prompt
	4:58	mmhmmmmhmmmm		
	5:08	Ah. For cryin out loud. There we go.		He's touching around in the game.
	5:24	I knew it wasn't true <?>		
	5:40	<quiet laughs>		Ferris wheel cut scene
	5:56	<laughs>		
	6:25	Remote control ferris wheel? / I so know what I want for Christmas		

as much as possible. The final step was to watch the digital video recording for a second time, noting any significant or interesting activity by the participant such as rotating the DS. Additionally, context for the participant's speech was added when necessary for clarification.

The final step in the transcription process was to "clean-up" the speech of the participant and the researcher as described by Blumberg, Rosenthal and Randall (2008). Dropped "g"'s were added to the end of words. For instance, thinkin' became thinking. Time fillers, such as uh and uhm were deleted. For the comparisons between puzzles, speech not related to the game, such as asking what time it was, was deleted. Grammatical errors and variations in dialect were not corrected.

### ***Coding.***

The first step in analyzing the think-aloud protocols and the interviews was to code the transcripts. A code is a word or short phrase that gives an essence of a piece of data (Saldaña, 2009). For the think-aloud protocols, the coding focused primarily on speech of the participant while engaged in solving a puzzle. The first step in the coding cycle was to read the transcripts and assign codes to significant phrases or ideas, known as open coding (Saldaña, 2009). For the think-aloud protocols, the unit of analysis was an idea or thought. Some codes, such as background knowledge, were adapted from Blumberg, Rosenthal and Randall (2008) while others, non-relevant speech, were taken from a previous research project using some of the transcripts. Additional codes were added as necessary to fully analyze the think-aloud protocols and interviews. A list of codes and a brief description of them can be found in Appendix H. The interviews and think-aloud protocols were coded independently.

Once the think-aloud protocols and interviews were coded for each participant, the codes were organized into larger categories. This enabled the identification of patterns and themes within the data.

### ***Triangulation.***

According to Patton (2002), triangulation involves combining different theories, methods, data or researcher in order to strengthen the study and to ensure consistency in the results. Three types of data were collected: think-aloud protocols, interviews and game playing logs.

### **Limitations**

Limitations to this research study include the small sample size, which limits the generalizability of the study to large or to different populations. Another major limitation is the alignment of the science reasoning skills used by the video games with the science reasoning skills tested. For the spatial reasoning assessment, the alignment is very good. However, for the general science reasoning skills, the video game taps into various different science reasoning skills, such as mathematical reasoning and probabilistic reasoning while the assessment focuses more on deductive reasoning and combinations. In other words, the assessment did not test all of the possible science reasoning skills that could be used to solve the various puzzles in the video games used in this study. There is also the potential problem with the level of the science reasoning assessment. The science reasoning tasks on the assessments may not have been at the same level of difficulty, with some assessments being more difficult than others. The only other option was to give the same assessment repeatedly, but because of the short time scale of the study, meant that practice effects could be significant. Additionally, science reasoning skills require

practice over a long period of time to improve. Students played the video games for about 30 hours. This may not have been enough practice over a long enough period of time to impact the science reasoning skills. Another limitation is the think-aloud protocols themselves. Even after practicing and multiple sessions, some participants still had difficulty or were reluctant to verbalize their thinking. In some cases, especially with Ryu, the thinking came so fast, that it was hard for him to verbalize what he was doing because he just knew what to do. This lack of verbalization also carried over into the interviews where some of the participants were not forthcoming in answering the questions and the researcher was unable to elicit more information from them. Finally, this research project looks at five participants at a particular instant in time. It is possible that the results would be different using five different participants or conducted at a different time.

### **Researcher Role**

The researcher conducted data collection, transcription, coding and analysis. As the study continued, some of the participants became more comfortable with the researcher and the research study, which can be seen by the increasing interaction between the researcher and the participant as the study progressed. Because the researcher was in the same room while the participants were playing, the participants would interact with the researcher, such as looking to the researcher for approval or to answer questions about the game. Finally, every participant reached an impasse during a puzzle or during game play and eventually the researcher would have to help the participant to solve the puzzle. The researcher would only offer to help after all three hints from the game had been exhausted, when the participant was clearly frustrated and

was ready to quit playing, or when the participant's problem solving activity became unproductive in moving them closer to the solution, which usually occurred sometime after the 15 minute mark for most participants. The researcher would then give the participant a clue or the next step, depending on the puzzle and give the participant a chance to solve the puzzle independently. There were a few instances where a participant became so frustrated that the researcher had to tell the participant what to do every step to solve the puzzle.

## CHAPTER 4: RESULTS

Using a mix of quantitative and qualitative methods for this case study, the research questions about how playing problem solving video games impacts the science reasoning skills of college students and what game playing behaviors are exhibited are explored. The results of the Science Reasoning Assessment (SRA) and the Purdue Spatial Visualization Test (PSVT) are considered first. The majority of the results come from analysis of the think-aloud protocols from the sample. Game playing episodes are compared between participants and as a function of time for each participant. Finally, the results from the interviews are used to support the conclusions from the think-aloud protocol.

### Participants

What are some of the similarities and differences between the five participants? Tables 3.1 and 3.2 give an overview of the characteristics of the participants. All of the participants are upper level undergraduates. Their ages range from 20 to 25, with Sora being the youngest and Kairi being the oldest. Ryu and Sora are males. Ryu is a physics major while the rest of the participants are education majors. Sora is a secondary education major while the other three participants are elementary education majors. Ryu has taken the most math and science courses, sixteen, with Sora taking the least at four. In terms of GPA, Ryu had the lowest at 2.43 and Lilo had the highest at 3.79. Sora, Peach, and Kairi had GPAs above 3.2.

In terms of video game experience, Kairi and Ryu both rated themselves as very good players and indicated they played every day. Sora played about every two weeks and rated himself as a moderately good player. Lilo only played every couple months but

felt she was an average gamer. However, during the think-aloud sessions, she would say she was not a gamer, especially when frustrated. Peach played monthly and indicated she was not very skilled. These characteristics are important to keep in mind when interpreting the results.

### **Reasoning Assessments**

Based on the responses to the Video Game Experience Survey (VGES), 18 initial respondents were invited to take the first reasoning assessment to determine if they qualified for the full study. The initial qualification was willingness to participate and an unfamiliarity with the video games used in the study. Scores on the first reasoning assessment, with 25 questions, ranged from 7 to 22. The median score was 15 and the mean was 15.2. There were two modes, one at 12 and one at 15.

The scores for the sample chosen for the full study ranged from 13 to 16, with a median of 15. Students with a score that fell in this range were classified as mid-level reasoners. They were chosen because it was felt that students of mid-level reasoning ability might benefit the most from the study. Because of the possibility of the ceiling effect, students with higher scores on the initial assessment were not included, even though they may have benefitted. To provide a comparison within the sample, an expert video game player and reasoner, defined as one who scored high on the initial reasoning assessment, and was also a science major (Ryu) was included. By including the science major, there would be a possible example of what science reasoning in a problem-solving video game looked like, as a science major would most likely be more familiar with science reasoning, so that it could be determined if the other participants were displaying the same behaviors or characteristics.



### Reasoning Assessment Results for the Sample

The participants completed the Reasoning Assessment at four successive times during the study. The scores for each participant are given in Table 4.1.

Table 4.1.

#### *Reasoning Assessment Results*

Subject	Reasoning Assessment 1	Reasoning Assessment 2	Reasoning Assessment 3	Reasoning Assessment 4	Percent Change
Kairi	15	14	10	8	- 47 %
Lilo	16	21	19	25	56 %
Peach	14	15	13	15	7 %
Ryu	22	21	17	17	- 23 %
Sora	13	15	10	12	- 8 %
Mean	16	17.2	13.8	15.4	

Table 4.2.

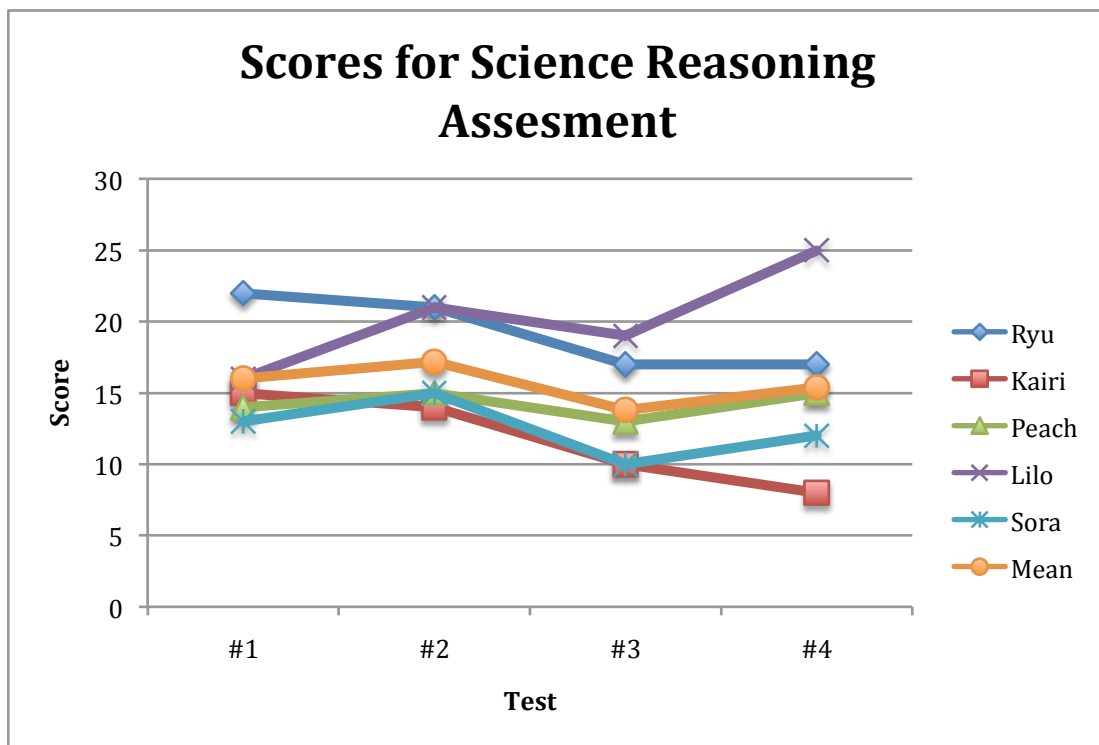
#### *PSVT Scores*

	PSVT 1	PSVT 2	PSVT 3	Percent Change
Kairi	17	13	16	- 6 %
Lilo	31	31	34	9 %
Peach	21	25	27	29 %
Ryu	34	36	36	6 %
Sora	12	20	19	58 %
Median	21	25	27	

Graph 4.1 displays the change in reasoning scores as the study progressed. As can be seen from both the table and the graph, scores on the Science Reasoning Assessment initially increased between Test #1 and #2, then dropped significantly for all participants for Test #3. Scores between Test #3 and Test #4 increased or stayed the same for all but one participant. This suggests that Test #3 was more difficult than the other three reasoning assessments. The overall mean for the sample decreased between Test #1 and Test #4. Only one participant's (Lilo) scores increased over the course of the

research study. For the rest of the participants their scores either decreased or remained flat.

There is a potential problem with Ryu's scores. After taking the last two assessments, Ryu confided in the researcher that he rushed through the tests and did not read them carefully. This would be reason enough to exclude Ryu's scores from quantitative analysis. As no in-depth quantitative analysis was conducted, Ryu's scores were included but their reliability is subject.



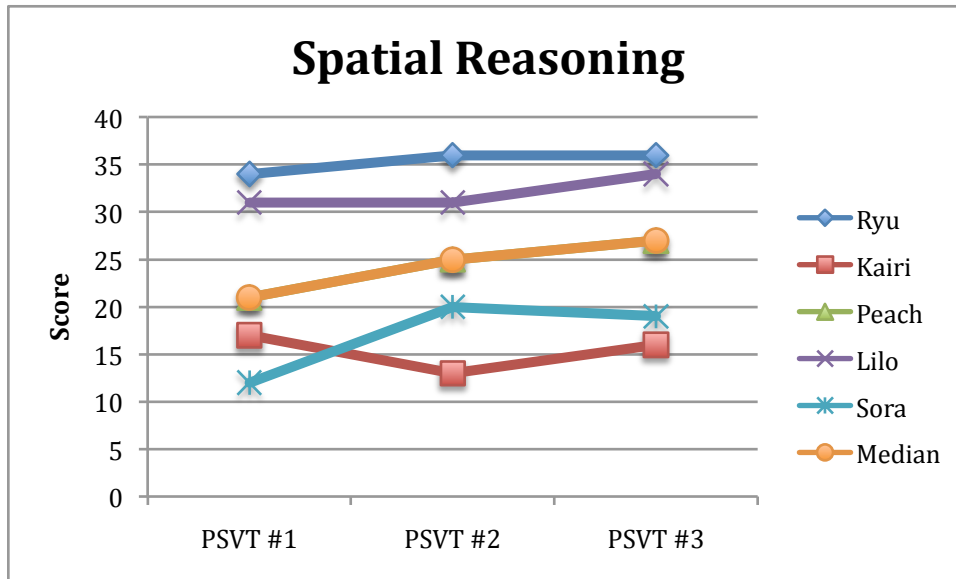
*Graph 4.1.* Scores for Science Reasoning Assessment

### Results of the PSVT for the Sample

Participants in the study completed the Purdue Spatial Visualization Test (PSVT) at three points during the treatment. Table 4.2 gives the results of the PSVT. Graph 4.2 displays the change in spatial reasoning for each participant. Because of the large spread in scores on each administration, the median was calculated instead of the mean. Except

for one participant, the scores on the PSVT increased over the length of the study.

Playing problem-solving video games does seem to increase the spatial reasoning of this sample of participants. Because it is a video game, there is an emphasis on the visual. Many of the puzzles in these problem-solving video games had a strong visual component that required spatial reasoning.



Graph 4.2. PSVT Scores

### Analysis of Puzzles

The first step in the analysis of the puzzles was to look at the data that came from the games themselves, such as number of puzzles solved and the time it took to complete the game. This enables one to look for possible relationships and to provide support for different conclusions. The next step was to analyze each puzzle in the macro sense and then micro sense, looking for overall patterns and patterns within the puzzles.

### General Game Analysis

Taken together, there are over 288 puzzles in the two problem-solving video games used in this study. Not every puzzle is required to advance forward in the game

or to “win” the game. There are, however, puzzles that are required; the player can not move forward in the game until that puzzle is solved. A minimum number of puzzles must be solved; it is unknown what that minimum number is. Based on the sample, it appears that the minimum amount of puzzles needed to solve the games is 75% or greater for each game. For PLCV, that works out to 101 puzzles and for PLDB, it works out to 114 puzzles. Except for Ryu, who was digitally recorded the entire time he played, the participants played anywhere from seven to 18 games during their game playing sessions. Table 4.3 gives the number of puzzles solved and the percent of the game that the participants played. The number of puzzles per participant per session varied depending on how well or how much difficulty the participant had during the think-aloud session.

The goal was to

have the participant play for 40 minutes a session for five sessions. However, during some sessions, participants had a great deal of trouble with one or more puzzles and it took them a great deal of time to solve one or more puzzles. Additionally, PLCV and PLDB are not just series of puzzles, one right after another, but rather a story with puzzles integrated into them. There are movies, searching and finding information between puzzles. It became more prudent to have the participants play a total of five puzzles in a session or for at least 40 minutes. In other words, if it took the participant only 20 minutes to solve five puzzles, the participant would then play for another 20 minutes. The participants, except for Ryu, solved 5% to 12% of the puzzles during the think-aloud protocol for each of the problem-solving video games. The lower percentage was Peach’s, who missed Session 2 and 3 of PLCV because she became so enthralled with the game that she completed it while on a weekend trip.

*Table 4.3.*

## Number of Puzzles Solved

Participant	Professor Layton and the Curious Village					Professor Layton and the Diabolical Box				
	Number Solved	% of Total	Number Think Aloud	% of Total	% solved think-aloud	Number Solved	% of Total	Number Think Aloud	% of Total	% solved Think Aloud
Ryu	112	83	112	83	100	115	75	115	75	100
Sora	87	64	14	10	16	91	59	15	10	16
Lilo	103	67	15	11	15	87	57	15	10	17
Kairi	115	85	14	10	12	115	75	10	7	12
Peach	107	79	7	5	7	114	75	18	12	16

Tables 4.4A-4.4E list the game session data for each participant at the start of the session. Session 1 is not included because all of the participants started at the same point. The data was taken from the problem-solving video games at the beginning of each session. For Ryu, who played the entirety of both problem-solving video games during the think-aloud protocols, the data is taken from about the mid-point of each game playing session. For Session 3, participants finished PLCV and began PLDB. Picarats are the money system for the problem-solving video games. Each puzzle is assigned a value of between 10 to 70 picarats, with harder problems having more value than easier problems. If an incorrect attempt at a puzzle is made, the number of picarats awarded decreases. For PLCV, the maximum number of picarats is 4175; for PLDB the maximum number is 4305. In both PLCV and PLDB, three hints are available for each puzzle in case the player gets stuck. However, these hints are not given freely. To get a hint, the player must use a hint coin, hidden throughout the game. There is a maximum number of hint coins. For PLCV, the maximum number of hint coins is 198. For PLDB, the maximum number of hint coins is 230. The number of picarats a participant has collected can be used to gauge how much difficulty a participant is having with a particular puzzle, as the number awarded decreases with every incorrect answer. A low number of picarats could mean that the participant is having difficulty solving the various puzzles and is making multiple attempts at solving them. It could also indicate that the participant is not exploring the game environment and finding extra hidden puzzles that would boost the number of picarats. The same can be said for hint coins. A low number of hint coins could indicate that the participant is using them to help solve the puzzles or is not exploring the game environment looking for hint coins. Finally, the time played

*Table 4.4A.*

Game Session Data for Sora

Session	Game	Puzzles Found	Puzzles Solved	Picarats	Hint Coins	Time Played
2	PLCV	64	62	1639	3	8 hr 21 m
3	PLCV	88	83	2390	6	12 hr 33 m
4	PLDB	51	50	1142	5	5 hr 29 m
5	PLDB	84	84	2129	6	9 hr 35 m

*Table 4.4B.*

Game Session Data for Kairi

Session	Game	Puzzles Found	Puzzles Solved	Picarats	Hint Coins	Time Played
2	PLCV	66	65	1842	10	7 hr 7 m
3	PLCV	113	112	3653	34	12 hr 12 m
4	PLDB	NA	NA	NA	NA	NA
5	PLDB	110	110	3063	42	13 hr 44 m

*Table 4.4C.*

Game Session Data for Peach

Session	Game	Puzzles Found	Puzzles Solved	Picarats	Hint Coins	Time Played
2	PLCV	NA	NA	NA	NA	NA
3	PLCV	109	107	3410	18	17 hr 18 m
4	PLDB	42	42	865	4	4 hr 58 m
5	PLDB	109	107	2755	27	14 hr 44 min

*Table 4.4D.*

Game Session Data for Lilo

Session	Game	Puzzles Found	Puzzles Solved	Picarats	Hint Coins	Time Played
2	PLCV	53	47	1245	37	6 hr 41 m
3	PLCV	103	98	2939	37	15 hr 18 m
4	PLDB	59	59	1347	14	7 hr
5	PLDB	82	82	2026	8	10 hr 32 m

*Table 4.4E.*

## Game Session Data for Ryu

Session	Game	Puzzles Found	Puzzles Solved	Picarats	Hint Coins	Time Played
2	PLCV	56	56	1528	26	5 hr 54 m
3	PLCV	101	100	3165	38	11 hr 7 m
4	PLDB	61	61	1413	8	7 hr 16 m
5	PLDB	116	115	2424	41	13 hr 44 m

can give an indication of how long a participant is spending on puzzles. A search of the different walkthroughs available for PLCV and PLDB uncovered that the fastest time to solve PLCV was 4 hours and 48 minutes. A minimum time to complete PLDB was not available; however, there are more puzzles in PLDB as well as extra game activities, namely serving tea, leading one to conclude that the game takes at least six hours to complete. If you subtract the minimum time to play the game, which includes all the movies and waiting while the game loads, from the time a participant took to play the game, it is possible to get a more direct comparison of the time spent playing puzzles. For example, subtracting the minimum time from Ryu's time to complete PLCV gives a total puzzle time of 6 hours and 19 minutes. Repeating the process for Peach, gives a total puzzle time of 12 hours and 30 minutes, roughly twice the amount of time Ryu spent solving the puzzles. This could indicate that Peach really struggled with solving the puzzles. However, in the interviews, Peach indicated she often went to the internet to find the solutions for puzzles that were more difficult for her. There is no pause button on the game, so the total time for game is from the time the game is loaded until it is finished. It is possible that she was distracted at some point and just left the game on. This happened in the think-aloud protocols with Ryu. Something in the game would send



him off on a tangent that he would talk about, stopping game play while the game was still active and time was running and he would need to be reminded to at least play while going off on tangents.

Appendices I and J list the time it took for each participant to solve each puzzle during the think-aloud protocols. The time is from when the puzzle first launches to the time the participant submits the correct answer. For Ryu, only the puzzles that the other participants solved are given in the appendices. For some puzzles, the times between the participants are similar while for other puzzles, the time it took to solve the puzzle varied greatly between participants. Most puzzles were solved in less than five minutes. When the time to solve a puzzle became greater than five minutes, it was usually because the participant was stuck and was trying various methods in an attempt to solve the problem. Sliding block puzzles, such as Professor Layton and the Curious Village (CV) 97: Princess in a Box, tended to take most participants a long time to accomplish, because the participants would get stuck in repeating the same moves over and over. Interestingly, Sora had the shortest time to complete a puzzle and the longest time to complete a puzzle. He solved Professor Layton and the Diabolical Box (DB) 61: Where's the Hotel in 30 seconds. It took Sora 30 minutes to solve CV 65: What's E?

There did not appear to be any similarities or patterns in the time it took participants to solve the puzzles, nor did there appear to be any relationship with any other factor. Perhaps had more puzzles or puzzles that were analogous to each other been played during the think-alouds, a pattern might have emerged. Many of the puzzles Ryu solved quickly were based on situations found in other games Ryu had played, such as DB 100: A Rickety Bridge, which according to Ryu is a classic puzzle. Whether or

not a participant solved a puzzle quickly or not seemed to depend on the context of the puzzle. For instance, with Sora, at the start of CV 71: Sausage Thief, he states "... I do better at these..." types of problems. He then goes on to struggle solving this particular problem. This could be because the context has changed from the other puzzles that are similar to it and Sora is unable to transfer the knowledge between concepts or use analogical reasoning.

### **Puzzle Analysis**

Over the course of the study, the five participants solved 345 puzzles during the think-aloud protocols: 162 from PLCV and 173 from PLDB, with the majority solved by Ryu. To analyze every single puzzle would not yield significantly more or different findings than a representative sample of puzzles. All of the puzzles can be classified into one of 12 different categories, listed and defined in Table 4.5. Additionally, Table 4.5 contains the number of puzzles in each category. Appendices D and E give the classification for each puzzle played during the study. The broadest category is Spatial. These puzzles can include mazes, path-finding or match sticks. Puzzles that are classified as mathematical reasoning require using hypothetical-deductive reasoning but the emphasis in the puzzle is more on mathematical processes.

The first step in determining which puzzles to analyze more fully and in depth was to examine how many of the participants solved each one. Puzzles that were solved by all five participants were given preference, then those solved by four participants and finally those solved by three. Five puzzles from PLCV were solved by all five participants while four puzzles from PLDB were solved by all five. The next step was to classify each puzzle by type. The goal was to choose puzzles that were good

Table 4.5.

## Types of Puzzle

Type	Description of Mental Skill	Example	Number in PLCV	Number in PLDB
Spatial	Using spatial relations or visual information	DB 3: The Right Key	44	48
Spatial/ Hypothetical- Deductive	Uses both spatial and hypothetical-deductive reasoning	CV 4: Where's My House	9	14
Hypothetical- Deductive	Uses hypothetical-deductive reasoning	CV 71: Sausage Thief	25	21
Combinatorial	Uses combinatorial	CV 98: Card Order	4	14
Probability	Uses probability	DB 64: Stones in a Vase	4	3
Proportional	Uses proportion	CV 96: Take the Stairs	5	5
Sliding	Pieces slide to free a block	CV 97: Princess in a Box	9	6
Math Reasoning	Requires the use of mathematical concepts	DB 89: Flower Bed Fun	10	15
Puzzle	Involved putting a puzzle together, similar to a jigsaw puzzle	DB 116: The Torn Photo	1	1
General Logic	Uses more general strategies and reasoning	CV 7: Wolves and Chicks	2	3
Optical Illusion	a subset of spatial with more of a visual trick to the puzzle	CV 3: Strange Hats	2	1
Miscellaneous	Do not fall into the other categories	DB 101: Disappearing Act 1	4	7

representations of the different categories as well as to have as many of the categories represented and have the puzzles in those categories as varied as possible. The final step was to examine the actual puzzle solving process for anything unusual. For example, did one participant solve the puzzle differently than the other participants? Was there a large difference in the time it took Ryu, the game and reasoner expert, to solve the puzzle

versus that the time it took for another participant? Did a novice game player and reasoner solve the puzzle quicker than Ryu? Based on this process, nine puzzles from PLCV and nine puzzles from PLDB, for a total of 18 puzzles, were chosen for in depth analysis. Tables 4.6 and 4.7 list the puzzles selected for analysis and which participants solved each puzzle.

*Table 4.6.*

PLCV Puzzles Chosen For Analysis

Puzzle	Type	Solved By
1	Spatial – maze	Ryu, Kairi, Sora, Lilo, Peach
2	Spatial – matching	Ryu, Kairi, Sora, Lilo, Peach
7	Logic	Ryu, Kairi, Sora, Lilo, Peach
9	Lateral/Spatial	Ryu, Kairi, Sora, Peach
63	Hypothetical-deductive / Math Reasoning	Ryu, Kairi
71	Hypothetical Deductive	Ryu, Sora,
95	Hypothetical-deductive / Math Reasoning	Ryu, Sora, Lilo,
96	Proportional	Ryu, Kairi, Sora, Lilo
98	Combination	Ryu, Kairi, Sora, Lilo

*Table 4.7.*

PLDB Puzzles Chosen For Analysis

Puzzle	Type	Solved By
1	Spatial – pattern	Ryu, Kairi, Sora, Lilo, Peach
2	Hypothetical-deductive	Ryu, Kairi, Sora, Lilo, Peach
4	Hypothetical-deductive / lateral	Ryu, Kairi, Sora, Lilo, Peach
64	Probability	Ryu, Lilo
77	Proportional	Ryu, Kairi, Sora
81	Combination	Ryu, Sora
89	Math Reasoning / Spatial	Ryu, Sora, Lilo
132	Math Reasoning	Ryu, Peach
135	Hypothetical-deductive / Math Reasoning	Ryu, Peach

### Results from Coding

The data was coded in order to be able to examine the types of reasoning used by the participants and to look for any potential patterns in the reasoning used to solve the

different puzzles. Coding the think-aloud protocols allowed comparisons to be made between participants. Additionally, the coding allowed for the examination of how reasoning may have changed over the course of playing time.

### ***Overall Reasoning.***

Tables 4.8 and 4.9 show the reasoning/thinking that each participant used or attempted to use when solving the puzzles analyzed. These two tables are more of a broad description

*Table 4.8.*

Reasoning/Thinking Used by Participants, PLCV

Puzzle	Ryu	Kairi	Sora	Lilo	Peach
1	POE	T&E/POE	POE	T&E/POE	POE
2	POE	POE	POE	POE	POE
7	Deduction/logic	T&E	T&E	T&E	T&E
9	Lateral	T&E/G	Lateral	X	T&E
63	HD/MR	G	X	X	X
71	HD	X	Fail HD	X	X
95	HD /MR	T&E	X	T&E	X
96	Proportional	X	Proportional/MR	Proportional/MR	X
98	Deduction/G	T&E	T&E	T&E	X

POE = Process of Elimination T&E = Trial and Error G = Guessing HD = Hypothetical-deductive MR = Math reasoning X = not played

As can be seen from the tables, the preferred reasoning strategies for participants tended to be trial and error or process of elimination. Trial and error involves unsystematically trying different possible solutions until one works. The quality of the trial and error reasoning differed between Ryu and the rest of the participants. As can be seen from Tables 4.8 and 4.9, Ryu's overall reasoning did not involve trial and error. He engaged in trial and error behaviors while solving some puzzles, for example in DB 1: Dr. Schrader's Map and in DB 135: The Magic Lock. Rather than using trial and error as

*Table 4.9.*

## Reasoning/Thinking Used by Participants, PLDB

Puzzle	Ryu	Kairi	Sora	Lilo	Peach
1	POE	POE	POE	POE/T&E	POE/T&E
2	POE	POE	POE	G/POE	G
4	Lateral	G	Lateral	G	G/T&E
64	Probability	X	X	G/Probability	X
77	Proportional	G	MR	X	X
81	Combination	X	T&E	X	X
89	MR	X	MR	MR	X
132	HD	X	X	X	T&E
135	T&E/MR	x	X	x	T&E

POE = Process of Elimination T&E = Trial and Error G = Guessing HD = Hypothetical-deductive MR = Math reasoning X = not played

the sole strategy to solve a puzzle, he used trial and error to test strategies derived by different methods of reasoning. In DB 1, he states his strategy at the beginning of attempting the solution and as he works towards the solution, he tries different pieces and checks against his initial strategy. After trial and error, the next most common overall reasoning strategy was process of elimination. Process of elimination is related to trial and error but is different as it tended to be more systematic and structured than trial and error. In CV 2: The Crank and Slot, all of the participants engaged in process of elimination. As Peach attempted to solve this puzzle, she examined each of the three options and verbalized “It’s not number 3 because it’s not the same shape...” and “It’d be 1 because the 2 are closest together,” leaving her with only one possible choice. All of the think-aloud protocols for this puzzle exhibit similar patterns of reasoning.

Ryu and Sora were the only two participants who used hypothetical-deductive reasoning. However, most of the time Sora’s use of reasoning was not successful. He would realize that he needed to use hypothetical-deductive reasoning but would be unable

to correctly apply it. A good contrast between the hypothetical-deductive reasoning of Ryu and Sora can be seen in CV 71: Sausage Thief. Ryu quickly deduced who was lying and who was telling the truth and identified which character in the puzzle was lying. Sora attempted to make the deduction to determine who is lying but was unable to draw the correct conclusion. For instance:

...B says that D ate them  
 And if A lying that means B didn't eat them  
 If C is lying that means then he did eat them  
 So well B can't be telling the truth then  
 B says he ate them all  
 So if D ate them all then B well  
 maybe that does work

Because if A is lying  
 then B did eat the sausages  
 If C well  
 there's a problem

If C is lying that means he did eat the sausages  
 But B says that  
 D ate all of the sausages  
 And if Well what if,  
 if D was telling the truth  
 then that means that B was lying since he did eat the sausages  
 But that would also mean that C

Ok the only one that says all is B  
 So the only case in which they ate all of the sausages  
 would be if D ate them all  
 Maybe they're sharing them again  
 So if

Well B could be lying because  
 D didn't eat them all  
 So if D was correct  
 that well if D was correct  
 that means that D didn't eat any  
 because B said that D ate them  
 he ate them all  
 So B could be correct and  
 D could still eat some sausages

Ok so that's working so far  
And Then C is lying and then B...

He draws the incorrect conclusion twice before finally drawing the correct conclusion, however; by this time, two of the four possible answers have been eliminated.

*Mathematical reasoning.*

All of the participants attempt to use mathematical reasoning when appropriate to a particular puzzle. Mathematical reasoning includes using math operations, processes and content knowledge to determine a solution. Sometimes the participants were more successful with it than others. DB 89: Flower Bed Fun required mathematical reasoning, specifically using geometrical reasoning and some spatial reasoning. Sora, Lilo and Ryu all struggled with this puzzle. Ryu struggled because he was trying to inappropriately use more advanced geometrical reasoning while Sora and Lilo struggled with visualizing the task correctly, in that they could not see what the puzzle was asking.

The sophistication of the mathematical reasoning varied between the participants. Ryu tended to use algebra and geometry whenever possible. The other participants tended to use basic mathematical operations. It is not clear why the other four participants did not use higher-level mathematics in puzzles that involved mathematical reasoning. Unfortunately, the participants were not directly asked about their mathematical reasoning, so there is no way to know why they did not use higher-level mathematics. Table 3.2 lists the number of college-level math and science courses taken by each participant. It is understandable why Sora might not have used mathematical reasoning, as he only had taken one college level math class at the time of the survey. Kairi, Lilo and Peach each responded that they had taken three, four or five college level



math classes at the time of the survey. As all of the participants were education majors, it is possible they counted their math methods courses as a college level math class.

Furthermore, they may not have been able to apply what they learned in their math classes in any effective way to solve the puzzles or even recognize when they could have used what they had learned to solve the puzzles. This conclusion can be drawn from examining the mathematical reasoning of Ryu while solving puzzles. Ryu constantly attempted to use algebra and geometry, even when it led him in the totally wrong direction. He was sometimes unable to apply his math content and process knowledge to the reasoning. If Ryu, who is more of an expert reasoner has difficulty, it seems unsurprising that students who are at a lower level of reasoning would have difficulty. A final explanation for this lack of sophistication with mathematical reasoning could come from Piagetian cognitive theory. Although it was not directly assessed, the lack of advanced reasoning might be because the participants have not reached the formal operational stage, but are at the concrete operational stage and therefore have not developed the necessary mental schema (e. g. Lawson, 1993).

#### *Proportional Reasoning.*

Closely related to mathematical reasoning is proportional reasoning, in which the relationship between two quantities is determined. Two puzzles examined in-depth required the use of proportional reasoning: CV 96: Take the Stairs and DB 77: Balancing Ornaments. Ryu, Sora and Lilo solved CV 96 while Ryu, Sora and Kairi solved DB 77. In CV 96, the puzzle states the amount of time it takes to travel from one floor to another. The player needs to determine how long it takes to travel between a different set of floors. In solving CV 95, Ryu quickly established a proportion to arrive at

the answer once he realized the number of floors changed. Ryu demonstrated reasoning consistent with formal operational reasoning as defined by Piaget (Thornton and Fuller, 1981). Lilo determined how long it would take to climb one floor and then added the times together. This is not proportional reasoning but rather a type of additive reasoning. Sora used proportional reasoning almost by accident. He attempted to determine how long it took to go up one flight of stairs so that he can add the time for each floor together. However, he did not know how to do long division. To solve the problem, Sora set up a proportion to determine how long it would take to climb one flight and then added that to what he knew. He did not realize he could have used the proportion to solve the problem. The reasoning used by Sora and Lilo shows that they are still in the concrete operational stage as defined by Piaget (Thornton and Fuller, 1981). In solving DB 77, Kairi did not use proportional reasoning at all and essentially guessed. After reading the instructions she announced "...I don't even know how to approach this one." She attempted multiple times to try and set up some kind of relationship between the three different ornaments in the puzzle but was unsuccessful. One attempt at a relationship was

...So 1 large equals 3 small  
 3 moons on this side with 2 circles.  
 It's heavier than  
 The stars.  
 2 moons are heavier than the 1 star and  
 Uhm  
 I don't even know. Let's see here.  
 1, 2, 3, 4, 5 moons on this side.  
 2 moons on that side.  
 5 to 2  
 1, 2, 3, 4,  
 4 to 1...

She had no idea why the answer was correct. Sora did not employ proportional reasoning in solving DB 77. He assigned numerical values to each of the different shapes and added up the different weights. Sora did realize that the middle string had no effect on the solution, as did Ryu. Ryu used proportional reasoning to solve DB 77. As Ryu solved the problem, he clarified the relationships between the different shapes and then related the different shapes to a common denominator. He then determined which shape he needed to keep everything in balance. This can all be seen in the following excerpt from Ryu's think-aloud protocol.

If we reduce these out to the lowest common denominator,  
 which is lights,  
 we have  
 let's see,  
 1 medium = 2 lights,  
 that's 4,  
 that's 7.  
 This one is 2 mediums  
 that's 4,  
 1 heavy is 3...  
 3 + whatever.  
 I mean, 1 heavy is 3  
 2 lights is 5 + 1 medium is 2  
 so that's 7.  
 So we need 1 light on this one.  
 So the star goes there.  
 Oops, or the crescent, I misspoke.

*Probabilistic reasoning.*

Only one puzzle included in the in-depth analysis required probabilistic reasoning, DB 64: Stones in a Vase, which was solved by Ryu and Lilo. The time it took Ryu to solve the puzzle is significantly longer than the time it took Lilo to solve the puzzle. Lilo appeared to guess the correct answer but in her explanation of her guess, she says "Cause I only have a little bit of chance not to get any coins." Is this sufficient

evidence of probabilistic reasoning or is it a lucky guess? Ryu, however, quickly realized the puzzle requires probability and identifies the problem as one of “...optimization of stones removed versus money possible.” As he reasoned through the puzzle, Ryu tried to avoid using probability and tried to set up an equation, “...Want to maximize n number of pulls, while still maintaining that  $n \leq 2n$ ...” He did go back to using probabilistic reasoning to finally solve the puzzle.

*Combinatorial reasoning.*

Only one puzzle out of the 18 fully assessed required combinatorial reasoning, DB 81: The Old Safe. Other puzzles, such as CV 98: Card Order, had elements of combinatorial reasoning. Combinatorial reasoning refers to reasoning out the different possible combinations of a set. Only Ryu and Sora solved DB 81. In DB 81, two codes must be matched using the information given. Ryu quickly realized which pieces of the code were in the correct place and deduced what needed to change. Sora clearly tried to deduce the correct answer as seen in this excerpt:

yeah so those are all the same  
Those are the right numbers  
But between here and there they move 4, 1 and 5  
So it's got to be 3  
But there it's telling me that  
But there 3's in different spot  
so it can't be right both times.

He struggled to determine how the codes are different and similar and the different possible combinations. He did not use combinatorial reasoning but a more reasoned form of trial and error. Interestingly, in CV 7: Wolves and Chicks, Lilo stated her strategy as “I am doing combinations to figure out the right combination to get this across.” What did she mean by combinations? Was Lilo trying to use combinatorial reasoning to solve

the puzzle? It did not appear from her verbalizations or movements that she was using any formal combinatorial reasoning but was randomly putting together wolves and chicks in the hope that it would work, such as "... Try this again, 1 chick goes back, 2 chicks on move back..." and "...I can do a wolf and a chick, No I can't do a wolf and a chick, I have to do 2 chicks, 2 wolves."

Out of the five participants, only Ryu used more advanced forms of reasoning such as proportional or hypothetical-deductive. He used these strategies from the beginning. For the other participants, they rarely used advanced reasoning and there was little if any change over the course of game play.

*Spatial reasoning.*

Many of the puzzles in PLCV and PLDB required the use of spatial reasoning to solve. One particular example is CV 2: The Crank and Slot. In this puzzle, the player is presented with a piece and three possible objects that the piece could fit. The catch is that the piece needs to be rotated so that it is viewed at an angle similar to the objects. Kairi realized that she could change the viewing angle of the piece and did so enabling her to view the piece more effectively. The other participants matched the different parts of the piece to the objects it could possibly fit. Only Sora needed two attempts to solve the puzzle.

Many of the puzzles required the use of spatial reasoning combined with another form of reasoning. An example of this is CV 9: One Poor Pooch. The first step in the puzzle is to realize what the dog will look like and then moving the matches so that the dog looks as it is supposed to. This first requires lateral thinking while the second part requires spatial reasoning. Once the participants realized what the dog needed to look

like, they were able to quickly determine how to accomplish the task using the matchsticks.

The participants physically rotated the Nintendo DS on certain problems. By rotating the DS, they were able to change their perspective, enabling them to find the solution. The participants could not accomplish the rotation mentally, but had to do the rotation physically. This happened frequently on spatial problems, especially ones that involved finding a specific shape in a block of random shapes, such as in CV 68: Hat Trick, which involved trying to find Professor Layton's hat. Another type of problem during which the DS was rotated by the participants were path puzzles, where the participant had to determine a specific path to travel, like in CV 59: The Longest Path.

The participants tended not to verbalize when they used spatial reasoning. The only clues to when they used spatial reasoning were when they mentioned rotating pieces or the DS to get a more useful perspective. Another clue would be when participants verbalized that they were moving a particular piece. At one point, Kairi was having trouble with some of the different cube puzzles. During one of the interviews, she mentioned that she had constructed a real cube to help her visualize the puzzle. She admitted she had an easier time manipulating the physical cube than the flat cube on the screen.

### **Evidence of thinking skills and processes.**

Eighteen puzzles completed by the five participants, with a reasoning strategy or process assigned to each were analyzed in-depth to look for evidence of thinking skills and processes. As discussed above, formal reasoning skills, such as hypothetical-deductive reasoning, were not prominently used by most of the participants. What types

of thinking skills, processes, reasoning and strategies were used by the participants while they were solving the different puzzles? Tables 4.10 and 4.11 give the different

*Table 4.10.*

Thinking Skills and Process for Professor Layton and the Curious Village from Think-Aloud Sessions

Puzzle	Ryu	Sora	Lilo	Peach	Kairi
1	DC	EJ, DC	S, EJ	MC	NC
2	MC	EJ	S	NC	EJ
7	S, MC	G, TE, MC, S	TE, S, MC, G	TE, EJ, MC	TE, S, MC
9	MC, DC	EJ	X	X	G, MC, TE, EJ
63	S, MR, Prop, DC	X	X	X	MC, EJ, G
71	MC	EJ, MC	X	X	X
95	MC, S, G, DC, EJ, MR	EJ, MC, MR	G, S, TE, EJ, MR, DC	X	X
96	Prop, MR, Pred, MC	MR, Prop,	Prop, MR, EJ	X	X
98	DC, S	MC, EJ, DC	S, EJ, DC	X	TE, EJ, DC, MC

NC = No Code DC = double checking MC = metacognition S = Planning a Strategy Pred = Predicting Prop = Proportional Reasoning MR = math reasoning TE = Trial and Error G = Guessing EJ = Evaluating/Judging X = not solved

processes used by each participant. It is possible that these different thinking skills and processes will form the foundation to support more formal reasoning in the future.

Overall, most of the participants used a variety of different processes and strategies while solving the different puzzles. This is in keeping with what has been seen in the literature, such as Henderson (2002). As seen with the overall strategy for solving puzzles, the participants, with the exception of Ryu, who used a variety of strategies, used trial and error most frequently.

***Working backwards.***

Even though there were puzzles that could have been solved with the working backwards strategy, such as CV 63, no evidence of the strategy of working backwards was found in the 18 puzzles analyzed in-depth by any of the five participants. The strategy of working backwards is most appropriately applied in problems where the final conditions are given and the initial conditions must be found. Another type of problem that can be most effectively solved using the process of working backward is route problems where the starting and ending points are known. The route between them needs to be found and is found by starting at the end and working towards the starting point. CV 56: The Lazy Guard, solved by both Lilo and Ryu, is an example of a puzzle that could have been

Thinking Skills and Process for Professor Layton and the Diabolical Box from Think-Aloud Sessions

Puzzle	Ryu	Sora	Lilo	Peach	Kairi
1	S, Pred, EJ, MC, TE	S, EJ	S, TE, EJ	TE, EJ, MC	TE, MC, EJ
2	EJ	EJ, MC, G	MC	G, MC, TE	G, MC, EJ
4	MC, EJ	EJ	TE	NC	S, EJ
64	Prob, MC, MR	X	Prob	X	X
77	Prop, EJ, MR	Prop, MR, EJ	X	X	MC, G
81	NC	EJ	X	X	X
89	MR, MC, G, EJ	MR, MC, S, G	MR, EJ, MC	X	X
132	S, EJ, MR, Prop, Pred	X	X	EJ, MC, MR, TE, G	X
135	MC, MR, TE, EJ	X	X	MR, MC, TE, EJ	X

NC = No Code DC = double checking MC = metacognition S = Planning a Strategy Pred = Predicting Prop = Proportional Reasoning MR = math reasoning TE = Trial and Error G = Guessing EJ = Evaluating/Judging X = not solved Prob = probability

backwards is most appropriately applied in problems where the final conditions are given and the initial conditions must be found. Another type of problem that can be most effectively solved using the process of working backward is route problems where the starting and ending points are known. The route between them needs to be found and is found by starting at the end and working towards the starting point. CV 56: The Lazy Guard, solved by both Lilo and Ryu, is an example of a puzzle that could have been



solved using working backwards. Instead Ryu and Lilo both tried to solve the puzzle working forwards and both struggled.

### ***Predicting a solution***

This was the least used thinking strategy by the five participants. When using predicting strategy or process, the reasoner anticipates or predicts what the potential goal or solution could possibly be and then works towards that solution. Only Ryu used prediction when solving some of the puzzles. He used prediction in two instances, CV 1 and CV 96. In DB 132, after he solved the puzzle, he said "...which is what I was expecting in the first place," but he never verbalized that thought or prediction at the beginning of the puzzle. None of the other participants used any form of prediction at the beginning of puzzle solving.

### ***Analogical reasoning.***

Another infrequently used form of reasoning for most participants was analogical reasoning. Analogical reasoning involves using previously solved problems or familiar experiences to solve a new problem. Only Ryu and Kairi used analogical reasoning.

Kairi used analogical reasoning in CV 9: One Poor Pouch. In this puzzle, Kairi connected the situation in the puzzle to her everyday experience: "...I'm also thinking of the last animal on the ground, their feet are up in the air..." and tried to solve the puzzle based on this information.

Kairi also recognized where she failed to use analogical reasoning. In CV 4: Where's My House, she struggled because she did not realize the direction the sun rises. Once she has solved the puzzle, she realized that she should have known what direction the sun rises because she drives to school in the morning and the sun is always in her eyes

because she is driving east. Interestingly in CV 63, Kairi realized that there are other puzzles she has solved in PLCV that are similar involving ages but that the stories are different. However, she was unable to bring that previous experience with those puzzles to bear in solving this puzzle. She had the knowledge and the experience but was unable to connect it to enable her to solve the puzzles. Most likely this suggests that she was not successful in understanding how to solve problems of this type.

Ryu used analogical thinking during the think-aloud protocols. He referred back to previously solved puzzles and to previous experience, most notably in CV 88: In a Hole. In this puzzle, a ball has fallen into a hole and you can only use a commonly available item to get the ball out. Ryu refers back to his experience of playing street hockey to solve this puzzle. Not only does Ryu bring previous experiences from outside the game to his play, he also brings his previous experience from playing earlier PLCV and PLDB puzzles and other video games to the forefront when solving a new puzzle. This occurs multiple times. One instance of bringing his experience from other video games occurred at the beginning of DB 100: A Rickety Bridge. Once this particular puzzle started, Ryu recognized it from a different video game series and mentioned how it has become a classic task in many different video games.

Not only was Ryu able to connect to his experience outside of PLCV and PLDB, he was able to connect with his earlier puzzle experiences to new puzzles later in the games. At the start of CV 95: A Magic Square, he immediately recognized it as the same kind of puzzle as CV 116: The Largest Total and used a similar strategy and process to solve it. When the same type of puzzle appears as DB 135, Ryu failed to mention that it was similar to CV 95; as both are magic squares and he seemed to

struggle a bit with solving DB 135. When he was stuck on DB 89: Flower Bed Fun; he tried to remember what he did the last time when he was stuck on a similar puzzle to arrive at the correct answer.

It is rather surprising that more participants did not use analogical reasoning. Many of the puzzles in PLCV and PLDB built upon one another other and became more complicated as the game advanced. One set, CV 53, 71 and 74, all involved determining who is lying based on a set of statements. Another set, CV 23, 24, and 78, involved three pitchers of different capacities which the player had to arrange to get a specific amount in one pitcher. Interestingly, both Lilo and Ryu mentioned this specific set of puzzles in the interviews as puzzles they hated and did not understand. CV 78: Water Pitchers was the only puzzle in PCLV Ryu was unable to complete on his own. He actually became so frustrated with this puzzle the researcher had to tell him step by step how to solve it so he could advance in the game. The same thing was seen in PLDB. DB 7, 83, and 84 were Tower of Hanoi problems that added more pieces as the game advanced. Another set from PLDB was DB 106, 107, 108 and 150: The Knight's Tour. Sora was able to solve these puzzles without much of a struggle while Ryu struggled. In fact, once he realized he could advance in the game without solving DB 108, he refused to solve it and skipped it. Perhaps the participants did use analogical reasoning but did not verbalize it. Without specific probing, it is impossible to determine whether they realized the puzzles were similar or not.

It is unclear why Ryu was able to use analogical reasoning and connect to his previous experiences while the other participants were unable to make connections. Based on the literature, the most likely reason Ryu was able to use analogical reasoning

was the fact he had taken 16 math and science courses at the time of the study. The range for the rest of the participants was four to eight. Robertson (1999) and Dunbar and Fugelsang (2005) both discuss how analogies are important in science. Rifkin and Georgakakos (1991) discuss how physics courses have a strong impact on science reasoning skills. Ryu is a junior-level physics major and has simply taken more advanced physics classes than the rest of the participants.

***Planning a strategy.***

How often did the participants verbalize how they were planning strategy or have some kind of process as a guide before they solved the puzzle? By planning a strategy, the participant stated or explained what he or she was going to do before doing it or what the overall process of solving the puzzle was going to entail. Planning a strategy is different identifying the problem or task in a puzzle. In identifying the task, the problem-solver is determining what he needs to do or what the problem is asking. Planning a strategy involves determining the steps or processes needed to answer the problem or completing the task. In the puzzles chosen for in-depth analysis, Peach did not verbalize or demonstrate any planning of a strategy either at the beginning of solving a puzzle or after becoming stuck on a puzzle. Sora and Kairi both mentioned a strategy at the beginning of two puzzles and on a different puzzle, after becoming stuck, verbalized a different strategy, a total of three times each. Ryu and Lilo both verbalized a strategy at the start of five puzzles. And after becoming stuck on two puzzles, both re-verbalized their strategy. Most of the time, it was evident from looking at Ryu's facial expressions and the pauses between verbalizations that he had a strategy in mind when solving the

puzzles, he just did not verbalize it. It maybe all of the participants had some kind of rudimentary strategies, but did not verbalize it.

***Evaluating and judging.***

One thinking process or strategy that was used by all the participants on nearly every puzzle was evaluating and judging. This strategy or process involves examining a potential solution or move and determining if it is the correct solution or move or if it is wrong, what could possibly be wrong and how to correct it. For most participants this process was verbalized with phrases such as “I think that’s right” or “That doesn’t fit/work.” This indicated that the participants are using some kind of higher order thinking and reasoning skills at some point in the puzzle solving process.

***Double-checking.***

Once a participant arrived at a solution, did he or she verify that the solution was the correct one or use double-checking? As can be seen from Tables 4.10 and 4.11, this strategy was not consistently used by all the participants across the different puzzles. None of the participants who played the nine puzzles analyzed in PLDB used double-checking. In PLCV, Ryu tended to use this strategy the most. Looking at the puzzles where double-checking was used, there is something common to all these puzzles: there is a condition the player can check against. For example in CV 98: Card Order, the puzzle directions give a set of conditions. Once the player has the cards in what he thinks is the correct order, he can then go back to those conditions and verify that his solution satisfies the different conditions. On any of the puzzles that had some kind of condition or way to self-check the answer, such as the CV 95: A Magic Square, it was more likely to promote participants using double-checking before submitting solutions.

***Guessing.***

One strategy that was frequently and repeatedly used by the participants was guessing. Ryu only guessed on DB 89: Flower Bed Fun when he was totally stuck and on CV 95: A Magic Square to get started. Most of the guessing, however, was not random for most of the participants on most of the puzzles. There were two clear examples of random guessing by two participants on two different puzzles. Kairi admitted to randomly guessing an age in CV 63: How Old is Mom. Peach made somewhat random guesses when solving DB 4: A Secure Room. As she attempted to solve the puzzle, she would spy random things in the room and try to justify that as the answer, but she would constantly admit she had no idea.

Lilo's guessing was interesting. On DB 64: Stones in a Vase, she read the problem and immediately said the answer. From her tone of voice, it was clear she was hesitant about the answer and was unsure as to why it was the answer. There are a few other puzzles where she was clearly guessing the answer, but guessed correctly. At one point in her later game play, she even admitted that there are some she "gets" right away. She appears to have some kind of intuitive sense about how to solve the puzzles but doesn't know how she is doing it.

It is likely that the guessing employed by most of the participants was not necessarily true guessing, in the sense that the participants had no idea as to how to solve the puzzle. What is most probable is that the participants had some kind of an idea as to what the answer was or how to proceed towards the answer, but it was intuitively known or it was mentally processed so fast that the participants believed they were guessing. In

other words, the participants were unable to verbalize the thinking and thought processes that went into their guessing.

***Trial and error.***

Closely related to the strategy of guessing is the process of trial and error. Trial and error involves attempting different possible solutions until one works. As mentioned before, trial and error was the preferred strategy for four of the participants. There was often a difference in how the participants used trial and error. When Ryu employed trial and error, for example on DB 1 or CV 95, his trial and error was more structured in that he had an underlying strategy to solving the problem. CV 95 was a magic square, which Ryu had a method to solve and it was just a matter of fitting the numbers in the method. Kairi employed trial and error on DB 1 as well and it was more structured then was typically seen in the other puzzles. Before working with each section of the map, she stated what she was going to do and then did it. She tested out each of the puzzle pieces a systematic way and eliminating the ones that do not work. This is in contrast to Peach's solving of DB 1 as she just tries different things until something works. There was no underlying method or strategy to Peach's trial and error. Clearly, trial and error was a successful strategy for most of the participants and they had no reason to abandon it.

***Metacognition.***

Metacognition broadly refers to "thinking about thinking." It is basically awareness of the cognitive processes and demands needed to complete a task. Some activities that are part of metacognition include planning how to approach a task, monitoring comprehension and evaluating progress on a task (Livingston, 1997). For the purpose of this study, metacognition refers to an awareness and recognition of one's

thinking, for instance, “I know I need to do this.” to solve a puzzle. All of the participants engaged in metacognition at various points in solving puzzles. Many times the metacognition occurred when a participant was stuck and were unsure of what needed to be accomplished next to complete the puzzle. For instance in the middle of attempting DB 77: Balancing Ornaments, Kairi blurts out “I’m just, I’m not even making sense to me.” She clearly has no idea what to do with this puzzle and recognizes it.

Sora’s metacognitive behaviors improved as the study progressed. By CV 65: What’s E, Sora was able to recognize that his thinking was incorrect but was unable to determine what to do to correct it. By DB 107: The Knight’s Tour 2, Sora was realized that he needed to formulate a strategy to complete the task and mentioned solving the puzzle in an efficient manner. No other participant’s metacognitive behaviors appeared to improve over the course of the study.

### **Game playing behaviors.**

#### ***Reading the directions.***

How often do the participants read the directions or refer back to the directions or other game text when solving the different puzzles? All of the participants read the directions for each puzzle, either out loud or silently to themselves. Participants referred back to the directions while solving problems whenever they became stuck or were unsure of what to do next. At times it seemed the participants thought if they just kept rereading or repeating the instructions, the answer would become clear. For instance, in CV 63: Mother’s Age, Kairi had no idea on how to determine the age of the mother from the given information. She restated phrases from the instructions three separate times before seriously attempting to solve the problem.



In some problems, like CV 98: Card Order, “hints” are given within the text of the instructions. Each participant referred back to the instructions multiple times. Kairi, Lilo and Sora would try a combination and then refer back to the instructions to verify that their particular combination satisfied the requirements. This occurred multiple times, essentially after each card placement. Each of them discussed their strategy or what the instructions meant between placing the cards. Ryu only referred back to the instructions once while sorting the cards. What makes this particular puzzle interesting is that all of the participants double-checked their answers. Ryu tended to double-check his answers regardless of the puzzle, but on this puzzle Lilo, Sora and Kairi also double-checked their answers. The most likely reason for why this occurred was the format of the instructions; the instructions were laid out in such a way to make double-checking a potential solution relatively straightforward. There were a list of conditions and the solution had to satisfy those conditions.

***Game interaction.***

How much did the participants interact with the PLCV and PLDB? What was the quality of the interaction? There are two types of game interaction: exploring the game and immersing one’s self in the game. Except for Ryu, none of the other participants immersed themselves in the game. Ryu was constantly making comments and offering opinions throughout his game play. As the story pace and action increases in PLDB, the player is getting very close to the end and critical information about the mystery is about to be revealed. Then comes DB 132: Sharing Paintings, which is introduced by Professor Layton exclaiming that we need to take a moment to clear our heads with a puzzle about portraits. Ryu started to laugh and exclaimed “Are you kidding, Professor, I

don't think I really have the time for this right now." Throughout his gameplay, with both PLCV and PLDB, Ryu made remarks about the scenery, the things the characters said and discussed the progress of the game. In PLCV, one of the characters disappears. Ryu expressed concern about the character and hoped they, Luke and Professor Layton, find him soon. About halfway through playing PLCV, Ryu declared that all the characters are robots. It turns out that he was correct. No other participant figured out the mystery. Throughout PLCV and PLDB, Ryu rolled his eyes at Luke and said things similar to "Sometimes I wonder about that boy." Ryu has taken ownership of his game playing experience. He even suggested other alternatives. For example in DB 4: A Secure Room, he suggested that instead of going through the window like the assailant, that he would flee using the chemistry set. In that same puzzle, Ryu claimed it was the dinosaur that had killed a character and that it was "a mobile heart attack machine" and he wanted one. No other participant interacted with the games and the characters in such an intense way. The other participants played but didn't interact and very rarely reacted.

Throughout PLCV and PLDB, there are hidden hint coins and puzzles, which can only be found by exploring the game, usually by clicking on different things on the screen. Again, except for Ryu, the other four participants did not explore the game very much during their think-aloud sessions. Given that all of the participants had hint coins, they must have done some exploration at some point but it was not in evidence during the think-aloud sessions. Most of the participants seemed to want to get through the games as fast as possible and that meant little to no exploring. Ryu, however, would explore the game and tap things that looked interesting to him. Interestingly, as the game progressed and Ryu got closer to the end and the revealing of the big mysteries, he stopped

exploring. At one point in PLCV and in PLDB, he acknowledged that he was most likely missing hint coins but he just wanted to get to the end and find out what happened. By not exploring the game, the other participants lost opportunities to practice and use various thinking and reasoning skills, because they are then not finding more puzzles, which could help them improve their reasoning skills.

### ***Self-reflection.***

Outside of the realm of metacognition, what kind of self-reflection did the participants engage in? Self-reflection was not evident on every puzzle but when it occurred, it occurred in conjunction with solving the puzzles. It was either self-congratulation or self-criticism. When a participant got a puzzle correct, they tended to congratulate themselves and cheer. Kairi and Lilo had a tendency to actually cheer when they got an answer correct. Ryu also tended to engage in this cheering behavior as well.

Perhaps the most distressing aspects of self-reflection occurred when the participants were stuck or frustrated. An example of this behavior can be seen in Kairi's solution of CV 2: The Crank and Slot. Kairi ended solving the puzzle with "I don't like to be wrong. Especially not in front of people." She restated this in many interviews. Lilo mentioned how she hates certain puzzles and "...always gets these wrong the first time." Ryu declared how he "...hates it when the blatantly obvious jumps out at you..." as well as having types of puzzles that were not his strong suit. Most distressing of all was Peach's reaction to DB 132. Peach was having difficulty with this puzzle and when she finally got the puzzle correct and was reading the explanation of the solution, she exclaimed "Oh duh. God I'm retarded." All because she had gotten the puzzle incorrect and had failed to see the solution.

***Game action.***

Sometimes during the think-aloud protocol, the participant would not actually say what they were thinking, but rather what they were doing, as if what they were doing was representing their thinking. Ryu had a strong tendency to do such things. In DB 4, Ryu had trouble determining the solution and started coloring and when prompted about his thinking he replied he was coloring. He colored on the screen to try and jumpstart his thinking. This phenomenon was most pronounced in puzzles where pieces needed to be moved, such as sliding block puzzles like CV 97: Princess in a Box 1. Lilo admitted she doesn't actually think during these types of puzzles but would rather "... just move the blocks." The transcript of Lilo and Kairi playing CV 97 consisted of statements similar to "...move this block here; move the green block there..." The same holds true for Sora's transcript of the game play; however, his game play was interspersed with predicting and planning. Sora knew what he had to do to get the Princess block out of the other blocks, such as moving certain pieces out of the way; however, he was unable to do so. He had ideas and strategies to solve the puzzle but was unable to implement them and ultimately needed the help of the researcher to complete the puzzle. On the other hand, Ryu hardly spoke as he solved the puzzle and had to be prompted to verbalize. He started the puzzle off by stating his strategy but was quiet while moving the pieces until he was able to free the Princess.

This phenomenon happened in CV 7: Wolves and Chicks as well. All of the participants would just say which animals and how many they were moving. There were times when the participants would mention why they were moving which animal, but

mostly, once they had settled on a strategy, it was mostly just which animals and how many.

It seemed that the participants were unable to articulate their thinking while moving the puzzle pieces. This was not unexpected, as it is one of the concerns with using a think-aloud protocol. The participant may not actually be able to articulate what they are doing or why they are doing it as they feel it is intuitive or that they are thinking too fast to verbalize. It may also be evidence of trial and error thinking. They may just be moving blocks, pieces or wolves to see if that will work without any strategy or thinking behind it. It would be interesting to further explore why the participants chose the pieces they did, as there must be some kind of strategy behind the choices.

### **Interviews**

The interviews were conducted to give the participants an opportunity to reflect on and explain or discuss their game-playing experience. One of the primary interview questions asked the participant to evaluate or name the thinking skills or processes and strategies they used when solving the various puzzles. The participants were free to give answers about any of the puzzles they had solved up to that point, whether or not they were solved during the most recent think-aloud protocol or at home. This question was asked during the interview after each think-aloud session. Table 4.12 lists the self-identified thinking skills, processes and strategies.

How do the thinking skills, processes and strategies identified as being used by the participants compare to the actual use of those particular thinking skills, processes and strategies during the think-aloud protocols? Both Lilo and Kairi mentioned working backwards as one strategy they used. However, in the 18 puzzles analyzed for in-depth

analysis, no participant used working backwards. Both mentioned this thinking process or strategy at the end of the first interview. None of the puzzles they solved in that session required the use of working backwards to solve. It may be that Lilo and Kairi do not understand the strategy of working backwards or they may have incorrectly applied it.

Peach and Sora both mentioned reading the directions as a thinking skill or strategy they used in solving the problems. Sora mentioned he “thought about the instructions.” This is seen in the puzzles used for analysis and throughout game play as all the participants read the directions. Perhaps what Peach and Sora meant was that they had identified the problem, which is the first step in the problem solving process.

Ryu, Lilo and Peach all mentioned math as one process they used to solve the various puzzles but did not elaborate what they meant or give any further description. However, Lilo and Peach only mention it one interview. This could be because the puzzles they had just solved were on their minds and they were puzzles that required math in that think-aloud session, meaning they are not referring to the puzzles they played at home. Ryu also mentions math as a primary strategy or thinking skill. However with Ryu, he did not typically just say “I used math” but rather identified the type of math he used such as geometry, algebra or some type of other higher mathematics. Similarly, Ryu was the only participant that mentioned using any science, in his case, physics, to solve any of the puzzles. In general, participants seemed unable to link science reasoning skills to the reasoning needed to solve the various types of puzzles and problems.

Ryu, Kairi and Peach all mentioned using logic to solve the puzzles during the interview. They did not explain in further detail what they meant by logic, however.

Table 4.14.

## Thinking Skills, Processes and Strategies Identified by the Participants

Interview	Ryu	Lilo	Sora	Kairi	Peach
1	Anticipatory thinking	Trial and Error Working Backwards	Anticipatory Thinking	Working Backwards Logical <sup>b</sup> Rotating the Game	Logic Common Sense Thinking it through
2	Math <sup>a</sup> Logic Variation	Process of Elimination Deduction	Reflective/evaluative Thinking Double Checking	Writing Out Information Manipulating Pieces	--
3	Guess and Check Devise a strategy/plan Math Common sense Process of elimination Deduction	Trial and Error Math Visual Deduction	Anticipatory Thinking Working Backwards Trying Different Things Evaluating Elimination	Trial and Error Previous Experience	Thought about them Lateral thinking Trial and error
4	Math Analogical Trial and Error Iterative Processes Breaking the Problem apart	Trial and Error	Rereading Instructions	--	Step by Step Read directions Looking at them
5	Analogical Physics Math	Trial and Error	Lateral thinking Thinking about the Instructions	Deductive reasoning Random Guessing	Math Writing Information out Visual Common Sense Guessing

a: For Ryu, math includes geometry, algebra and elements of calculus. For the other participants, math generally refers to basic operations, such as addition; b: Her description sounds more like Process of Elimination or Trial and Error

Looking at the puzzles that correspond with the interview, it was not clear when they actually used logic, or what they considered logic. Kairi described her thinking as

such: “then others were just like logical, the house one, you look at the roads and see if it’s a dead end or to another village.” Evidence of formal logic is lacking. It is possible they used some form of informal logic or deduction. It is much more probable that the participants thought they were engaging in logic but in reality were not.

Both Ryu and Kairi mentioned in the interviews using common sense to solve some of the puzzles. Neither participant gave any further explanation or examples of what they meant by common sense. It is not obvious from the actual game play where and when these two participants applied common sense.

Ryu and Sora both mentioned using anticipatory thinking to solve the puzzles. They both mentioned this in the first interview, when both of them would have played the first five puzzles. Sora did not mention anticipatory thinking by name but rather described his thought process as “thinking about what happens next before I did it.” Ryu also did not mention anticipatory thinking by name but rather described his thinking as trying to approach it with the final solution in mind. What is interesting is that neither participant mentioned using anticipatory thinking in any further interviews. It is possible that either or both participants still used anticipatory thinking but did not mention it or they may not have believed or felt that they used anticipatory thinking.

Lilo, Sora and Kairi all mentioned using the strategy of working backwards to solve the various puzzles. However, based on the think-aloud sessions for the puzzles analyzed in-depth for this study, there was no evidence of the strategy or process of working backwards. It could be that the participants did use the strategy for working backwards in puzzles either not analyzed or in puzzles they solved at home. It is possible



that the participants do not understand or do not correctly apply the strategy of working backwards. In the third interview, Sora said

Trying to think about where I wanted to end up and try and work backwards.

Instead of just rushing forward with whatever the instructions are. Try to think about well this is the answer I'm looking for. And if I work backwards on how to get there and see if that works.

What he described sounded like working backwards and that is what he defined it as.

However, in the working backwards strategy, the end goal is known and the initial condition must be determined. Knowing that an answer must be found and trying to get there is not working backwards. Lilo mentioned backwards thinking which may refer to the strategy of working backwards or it might be something completely different. Kairi mentioned the same thing, except she called it a "backwards method."

Both Lilo and Peach mentioned "visual" as a strategy or thinking process in the interviews. To them this strategy was just looking at the puzzle. Lilo says "there were some that I used just visual, looking at it." She then references DB 1 and mentions that if the pieces do not "...connect visually, that's not where it goes." Peach mentions that on some of them she "... could visually do a lot of stuff." In the fourth interview, Peach says, "I just read over directions and then look at the puzzle." There is some thinking process or reasoning occurring; however, the participants are unable to verbalize what that reasoning is.

Both Sora and Peach mentioned lateral thinking, or thinking outside the box as one of the thinking skills they used when solving some of the problems. Thinking outside the box refers to looking at a problem from a different perspective or in a new

way. Sora mentioned he had to think outside of the box to “...accomplish some of the tasks.”

For most of the interviews, the participants identified lower order thinking skills or strategies as what they were using. In interviews with Ryu and with Kairi both mentioned using analogical thinking, or relating a current puzzle to a previously solved puzzle. Ryu did use analogical thinking during the think-aloud protocols. He referred back to previously solved puzzles and to previous experience. Kairi also referred back to previously solved puzzles and to previous experience.

There were 23 interviews between the five participants. What thinking skills and strategies were mentioned most frequently? Deduction was mentioned by Ryu, Lilo and Kairi. However, except for Ryu, deduction was not a frequently found in the think-aloud protocols. No one used formal deduction, but any deductive reasoning that took place was more informal in that the premises and conclusions were not explicitly stated or obvious. It is interesting that Lilo mentioned deduction, especially since Lilo’s preferred strategy was trial and error. It is likely that Lilo and Kairi do not fully understand what deduction is or know how to apply it.

The next commonly mentioned “thinking” skill or process was guessing. Ryu, Kairi and Peach all mentioned using this strategy. However, Ryu mentioned checking the result of his guess. Ryu’s use of the guessing strategy was more sophisticated, as he tended to check what he guessed the answer to be. Kairi fully admitted to using random guessing in the last interview. Peach also admitted to using guessing in the final interview. Clearly, they felt that the strategy of guessing worked for them.

Closely related to guessing is the use of the strategy of process of elimination. Ryu, Sora and Lilo each mentioned this strategy as one they use to solve the puzzles. These participants recognized that they were using this strategy. Peach and Kairi also used process of elimination to solve puzzles but they did not recognize it. It may be that these participants, who both used a strategy of guessing, conflated the idea of guessing with process of elimination.

The most commonly mentioned strategy was trial and error. Every participant admitted to using trial and error at one point. For Lilo, it was her go-to strategy and she mentioned using it in four out of the five interviews. In the last two interviews, it was the only strategy she claimed to have used, which is not supported by her think-aloud protocols. Sora, Kairi and Peach all stated they used trial and error in the third interview, which occurred at the end of PLCV and the beginning of PLDB. Ryu also mentioned using trial and error. Clearly, this was a strategy the participants recognized using and were able to use. This strategy worked for them.

Peach acknowledged she “thought about them” and used “thinking it through” when asked what thinking processes she used to solve the puzzles. She seemed unable to further clarify what she meant by thinking it through. She did not have the ability or the vocabulary to further analyze her thinking.

Sora recounted using more metacognitive processes in his solving of the puzzles. Primarily, he mentioned using reflective and evaluative thinking in that he started reflecting on what he was thinking and began to evaluate his methods. In many instances, Sora was able to recognize that he was going about the problem incorrectly, but was

unable to determine what to do to move forward. Sora's use of metacognitive strategies could also be seen in the think-aloud protocols of game playing sessions.

Ryu identified using a wide variety of thinking skills, process and strategy over the course of the interviews and identified using 15 different strategies. Compare this to Lilo, who only used six strategies. As a more expert reasoner, Ryu was able to call upon many different reasoning skills. Furthermore, he was able to recognize that he would need to use more than one strategy to successfully complete the different puzzles in the game.

Except for Ryu, none of the other participants trended towards using more sophisticated thinking skills or strategies as the study progressed. This could be for a variety of reasons. One might be that the participants did not need sophisticated reasoning to be successful at solving the puzzles and moving forward in the games. Because they could get by with guessing and trial and error, they tended to stick with that. This behavior, using the path of least resistance, is consistent with the discussion in Koster (2005), who explains how brains are inherently lazy and prefer to not have to actively think or call upon cognitive load. It may not have been efficient for them, but it worked. There is a significant difference between being successful in the game and being successful at learning.

### **The Role of Content Knowledge**

The majority of the puzzles found in PLCV and PLDB require no advanced content knowledge. When content knowledge was needed, it tended to be basic information such as the direction the sun rises. The most common type of content knowledge needed to solve puzzles was mathematical in nature. The player needed to

know operation facts and processes to solve a variety of puzzles, such as the CV95: The Magic Square, which asked the player to put the numbers 1-9 in the correct order such that all the rows, columns, and diagonals, added to the same number. The other type of mathematical content knowledge needed was geometrical content knowledge, such as shapes, area and volume formulas, and relationships.

One puzzle that required some content knowledge was CV 4: Where's My House. In this puzzle, the player is given a map with houses and given directions to find the correct house. One of the clues is "...you'll come face to face with the morning sun." Three of the participants knew that the sun in the morning was in the east and were able to solve the puzzle without too much difficulty. Kairi, however, thought the sun rose in the west and attempted to find the correct house based on that misconception. At one point during solving the puzzle, Kairi realized that she has two possible correct answers leading her to believe that the process she was using to solve the problem was incorrect and that she was misunderstanding the task in some way. Kairi struggled with the puzzle for over eight minutes before the researcher asked her if she is sure the sun rises in the west. Once Kairi realized that she had the direction of the sun incorrect, she was quickly able to solve the puzzle correctly. Sora also did not know that that sun rose in the west and needed a prompt from the researcher to get started on the correct path towards the solution.

Puzzle DB 89: Flower Bed Fun required geometry content knowledge, specifically how to find the area of an irregularly shaped object. In this puzzle, a player needs to find the area of a colored section of a figure, composed of a circle and a square with concave sides. Ryu, Lilo and Sora all had difficulty with this puzzle. The first step

performed by each participant was the determination of the area of the circle, leaving them to struggling with how to find the area of the concave square. In geometry, it is often necessary to redraw a figure so that the relationships are clearer. This was the case with DB 89. Redrawing the colored section made it easier to find its area. It was only after using all the hints, and the assistance of the researcher that the three participants realized they needed to redraw the colored section.

An interesting example of the role of content knowledge in playing problem-solving video games is the case of Ryu. At the time of the study, Ryu had taken enough math classes to qualify for a minor in math with his physics degree and therefore had a significant amount of mathematical content knowledge. Sometimes it worked to his benefit and other times to his detriment.

One puzzle Ryu was able to effectively solve using his mathematical content knowledge was CV 22: Pigpen Partitions. In this puzzle, the goal was to create pens for seven pigs using three pieces of rope. Ryu looked at the puzzle, said he could solve it using Reimann Sums and proceeded to solve the puzzle in under a minute. Ryu was able to effectively use his content knowledge to solve the puzzle without difficulty.

However, Ryu's content knowledge created some problems when solving problems. The most striking example of this is CV11: Arc and Line. In this problem, a rectangle inscribed in a quarter of a circle and the diagonal of the rectangle must be found. If the diagonal is redrawn, it can be seen that it is actually the radius of the circle, which was given in the puzzle text. Ryu tried three different methods, the Pythagorean theorem, special triangles, and trigonometry to solve the puzzle, before resorting to

guessing based on what he had calculated using the Pythagorean theorem. Ryu had the content knowledge but was not effective at applying it correctly at times.

### **Cognitive Flexibility**

None of the participants got every puzzle correct on the first try. For many puzzles, the participants needed multiple attempts to solve a puzzle correctly. When a participant was unable to solve a puzzle, how did they move forward? Most frequently, they accessed the hints made available from the game. In some instances, for example most notably Kairi, participants looked online for solutions or assistance with the puzzles. However, during the think-aloud protocol sessions, participants were not able to look answers up online. Only as a last resort, such as when they were hopelessly stuck or incredibly frustrated, did the researcher assist them in solving the puzzle. How did they move forward? Were they able to change their thinking or perspective in order to solve the puzzle?

In most cases they were not able to formulate another method of solving the puzzle and would try the same things over and over. This behavior occurred in all participants at one time or another. For Sora, it most frequently happened with puzzles that required moving pieces such as sliding blocks or CV 7: Wolves and Chicks. Sora recognized that he was not being productive in his movements and was doing the same things over and over again. He was unable however, to figure out what to do differently. In CV 65: What's E? Sora realized that he had to count something. He says it over and over in the think-aloud session. He was unable to change his perspective and figure out what to count or if he really needed to count. He struggled with this puzzle for 30 minutes before being able to determine the answer with a hint from the researcher.

Despite being a more expert reasoner, Ryu did not display much cognitive flexibility. Ryu's go-to strategy tended to be algebra and geometry. Whenever it was remotely possible, Ryu tried to do puzzles using some form of math, even if it was to his detriment. This was clearly illustrated in CV 11: Arc and Line. To solve the puzzle efficiently involves recognizing that the solution is given in the illustration. Initially Ryu attempted to solve the problem using the Pythagorean theorem. When this failed, he moved on to using special triangles and trigonometry. When these failed to solve the problem, he was unsure of what to do next and ended up making an educated guess based on the Pythagorean theorem. Had Ryu redrawn the puzzle image he might have seen the answer. However he was so focused on using math that he was unable to change his fundamental strategy. Unlike the other participants, Ryu recognized in the interviews that he tried to use math as a strategy whenever possible and furthermore recognized that sometimes it hindered his ability to solve the puzzles.

#### **DB 61: Lateral Thinking or Trickery**

For most puzzles, Ryu, the expert reasoner and game player, solved them quickly and relatively more efficiently than the rest of the participants. There were a few puzzles that took him as long as others in the sample to solve. However, one glaring exception to this is Puzzle 61: Where's the Hotel in PLDB. In this puzzle, the player is presented with four different buildings and asked to choose which one is the hotel. There are no signs and the instructions only say to study the area very carefully. Sora and Lilo were able to solve the task almost immediately. They both read the directions and almost immediately saw the solution. Sora solved the puzzle in 30 seconds and Lilo solved it in 38 seconds. This was the fastest puzzle they solved in PLDB.



When examining the possible answers, Peach initially disregarded the correct one because it didn't look like a hotel, but "...the fact that there's 2 doors that are looks more like a house or an apartment." She examined each building and chose the one that looked more like a hotel. Eventually, Peach chose all of the buildings and found the correct one because it was the only one left. As she chose the only answer left, she expressed how it must be the answer but she had no idea why and she did not think it was the correct answer. Once the game explains why it is the correct answer, she seemed to accept it. It took Peach 2 minutes and 32 seconds to solve this puzzle.

It took Ryu 2 minutes and 25 seconds to solve DB 61 and, like Peach, he chose all of the incorrect options before only being left with the correct option. As he chose each option, he gave a reason for choosing it. For example, he chose his first incorrect choice because it seems to have features you would expect in a hotel such as double doors, many rooms and a penthouse on top. As the options are eliminated, he struggled to come up with reasons for his choices. For example, he hesitated making another choice because it looked more like a factory. Eventually he is left only with the correct answer. As he read the explanation, he exclaimed that it "...is the stupidest thing I've ever seen" and "That's so dumb". He protested that it was not a puzzle but rather "...it was just trickery."

When does a puzzle require lateral or out-of-the-box thinking and when is it just a trick? Lateral thinking involves generating novel solutions to problems as well as being able to change one's perspective (Culatta, 2011). Sora and Lilo were able to "see" the novel solution while Peach and Ryu were not. Why is there a difference in how these participants see this particular puzzle? Perhaps it is the lack of ability in employing a variety of strategies in solving other puzzles. Sora and Lilo both try to solve puzzles in

some intuitive way and always seem to look for the easiest possible solution. Ryu, however, almost always planned out a strategy and had an idea where he wants to go with a puzzle and its solution. When the puzzle failed to conform to his strategies or his frames of reference, he was unable to change his perspective to solve the tasks. DB 61 may very well be a trick. It does not require any kind of logic or deduction to solve, but there are many problems in the world that do not require them either. Perhaps the value of DB 61 is to help students develop strategies for when their normal ways of attacking a problem or task fail. In that regards, DB 61 maybe a good example of the need for lateral thinking.

### **Conclusion**

Using qualitative and quantitative data, the use of reasoning skills to solve problem-solving video games has been explored. Analysis of the results of the Science Reasoning Assessments and the Purdue Spatial Visualization Test has been presented and discussed. Using the think-aloud protocols and the interviews, a qualitative analysis has been presented. The evidence seems to suggest that the participants used very little formal reasoning and if formal reasoning was used, it was almost by accident. What does this mean in terms of the research questions?

## CHAPTER 5: DISCUSSION AND CONCLUSION

Did playing two problem-solving video games affect the science reasoning skills of a small, select sample of college students? What conclusions can be drawn from terms and parameters of the study?

*Research Question 1: In what ways do problem-solving video games affect the reasoning of students?*

*Do playing problem-video games help students develop their science reasoning?*

Based on the results of the Science Reasoning Assessment (SRA), the science reasoning skills of the participants in the sample did not improve as can be seen in Table 4.1. Only two students, Peach and Lilo, increased their science reasoning as measured by the SRA. Peach's science reasoning improved by 7% over the course of the study. Lilo showed dramatic improvement in science reasoning as measured by the SRA, as her score increased from 16 to 25, an increase of 56%. However for Ryu, Kairi and Sora, their science reasoning under the design of the study as measured by the assessment decreased. Both Kairi's and Sora's scores had increased from SRA #1 to SRA #2, but then sharply decreased with SRA #3. Sora's scores had started to rebound at the end of the study but Kairi's scores successively decreased. Ryu's scores decreased and then stabilized.

What could explain these results? There may be a variety of reasons for this. The most straightforward reason is the lack of alignment of the problem-solving video games and the SRA. The SRA tested primarily logic and hypothetical-deductive reasoning, with some combinatorial and probabilistic reasoning problems included. The problem-solving video games used a variety of different types of problems, from logic to mathematical

reasoning to lateral thinking. It maybe that there was quantifiable improvement in types of reasoning not tested for by the SRA. A more sensitive or comprehensive assessment may give different results.

There may have also been an issue with the difficulty of the SRA. The SRA was drawn from different administrations of the GRE. Given that the participants were junior and senior undergraduates, which is the educational level of most GRE takers, it was thought to be at an appropriate level. It was assumed that the difficulty level of each section would be similar. However, it appears that assumption is false based on the results from the SRA. Every participant experienced a decline in score for SRA #3. Either the SRA #3 was more difficult than the other SRAs or there is some other explanation outside the scope of this study. Another potential problem is the seriousness of the participants taking the SRA. Ryu mentioned that he had quickly taken SRA #3 late at night while he was tired and actually later admitted taking all of the tests late at night. Kairi took the final SRA #4 while in China as a student teacher. Both of these extenuating circumstances may explain the decrease in scores.

Another possible reason for the overall decline is a possible decrease in interest and fatigue over the course of the study. It became increasingly difficult to get the participants to complete the science reasoning assessments within a week and some participants did complain about the assessments being long, hard and confusing. For the entire time he worked on PLCV, Ryu played after a full day of work and classes. It is likely he was too fatigued cognitively to benefit from the game. For the other participants, think-aloud sessions occurred in the late afternoon after classes. In a study to examine the effects of cognitive fatigue on test-taking, Ackerman and Kanfer (2009),

discuss how the literature does not support cognitive fatigue in terms of impacting results. However, there is support for subjective cognitive fatigue with increasing time-on-task. Some symptoms of subjective cognitive fatigue include lack of interest, lack of motivation, task aversion, difficulty in concentrating and physical symptoms such as muscle aches (Ackerman & Kanfer, 2009). It is the lack of interest, lack of motivation and task aversion that are most relevant to this study. If the players lose interest or motivation, they stop playing, thereby not reaping the cognitive benefits. One of the participants, Kairi, often remarked outside of the “official” think-aloud protocol, how she was totally addicted to the two games and could not stop playing. She was desperate to know what happened next in the story. It could be that she played so fast trying to move the game forward that she did not spend sufficient time on analysis and reflection of the task and its solution.

Do the think-aloud protocols show an increase in science reasoning by the participants? That depends on the participant and the type of problem being solved. Some participants, like Sora, moved towards using more structured reasoning when solving problems. Other participants, like Lilo, were so successful with their guessing strategy that they did not appear to move towards more structured reasoning. Part of the issue stems from the limitations of the think-aloud protocol. Often times a participant is unable to articulate or verbalize what they are thinking making it appear that they are guessing. The participant may intuitively have a strategy to solve the problem but is unable to say why that strategy works or why they chose that particular strategy. They just know that they know it. However, when asked in the interview what thinking strategies they used while playing the game and solving the puzzles, the participants

would often answer trial and error or guessing. Either they are unable to reflect and then analyze their thinking or they relied on strategies they were familiar with and that were successful for them in the past. Participants, other than Ryu, may have used other strategies and processes of reasoning, but were unable to articulate them.

Based on the results of the SRA and the think-aloud protocols, problem-solving video games were not shown to improve science reasoning skills. The most likely explanation for why the science reasoning skills did not improve is two-fold. The first and most likely explanation is the limited amount of time spent playing the problem-solving video games by the participant. Each participant played the games for about 30 hours over the course of six months. Science reasoning, like all skills, takes time and practice to develop. It is probable that the participants simply did not have enough practice using science reasoning. A longer study using more problem-solving video games may have shown an increase in science reasoning skills. A second possible reason for the lack of improvement in science reasoning skills is the limited opportunities for discussion and guided reflections before and after a puzzle with the participants. The video game logs were supposed to fulfill this function and be a way to help the participants reflect, but the participants did not fill them out. Because the participants were successful with their strategies of trial and error and guessing, they had no impetus to change how they reasoned. Had they been guided as they played or had discussed different reasoning approaches, the results may have differed.

*Do problem-solving video games help the students increase their spatial reasoning?*

Based on the results of the PSVT, the problem-solving video games did improve the spatial reasoning of the majority of the sample. Only one participant's score decreased and it was a slight decrease of only one point or 6%. The two problem-solving video games did have a significant number of puzzles, such as match stick figures and pattern recognition that required spatial reasoning. Other problem-solving video games may not emphasize spatial reasoning as much as the Professor Layton series of video games, but previous research has shown a link between spatial reasoning and the playing of video games.

Why the increase in spatial reasoning? One possible explanation is the amount of practice over the length of the study. By playing the problem-solving video games, the participants were able to practice their spatial reasoning skills through puzzles that required solving mazes, re-orientating the problem spatially and pattern matching. Another possible explanation is the practice effect of the test. There was only one form of the PSVT available. The participants in the study took the test three times over the span of six months. It is possible some recall occurred from testing session to testing session.

Do the think-aloud protocols support the conclusion that problem-solving video games improve spatial reasoning? That depends. Participants did not specifically state they were using spatial reasoning to solve a problem. If their actions while solving the puzzles are examined, there were instances of spatial reasoning being displayed. For instance, in many of the spatial problems, Ryu and Kairi would rotate the DS to facilitate

solving the problem. Rotating the DS helped them examine the puzzle from another angle. In other instances, participants would redraw the puzzle on a piece of paper or using the memo function of the DS to try and understand the problem spatially.

Based on the PSVT results, the think-aloud protocols and the connections with previous research in the literature, such as Dorval and Pepin (1986), it can be concluded that playing problem-solving video games have the potential to increase the spatial reasoning of college students. Furthermore, because spatial reasoning is an element of science reasoning, it is possible that science reasoning skills could be improved.

*Research Question #2: What cognitive processes do students of different reasoning use when playing problem-solving video games?*

While playing the problem-solving video games, the participants used a variety of cognitive processes as discussed in Chapter 4. In the interviews, the participants tended to identify trial and error, guessing and working backwards as the thinking processes or strategies they used in solving the puzzles. However, based on the coding, the participants used a wider variety of cognitive processes, as seen in Tables 4.12 and 4.13. As was discussed earlier, except for Ryu, the participants did not use higher-order reasoning. The most used strategy for solving the puzzles was trial and error.

As the study progressed, there was some change in the cognitive processes used by the participants. For example, Sora started using more metacognition as the study progressed. However, none of the participants started using more formal or structured reasoning as the study progressed nor did they appear to improve at using the forms of reasoning they were relying on to solve the puzzles. Ryu is the exception. He was using more formal reasoning and strategies from the start of the study. In the majority of



instances, Ryu was also able to implement his cognitive processes to the effect of solving the puzzles quickly. He also spent less time “stuck” than other participants and less time repeating the same actions that did not help guide him toward a solution. As an expert video gamer and reasoner, Ryu exhibited higher or more formal reasoning than the other participants while solving the different puzzles.

*Research Question #3: What are the differences in effective game play based on level of experience?*

*What similarities and differences are observed between expert and novice game players in terms of cognitive processes and game play?*

There were significant differences in cognitive processes between the expert reasoner and the rest of the sample. Ryu almost never resorted to guessing. Even when using the trial and error strategy, he had a more methodical way of applying the strategy whereas the other participants did not apply the trial and error strategy methodically. Ryu interacted and reacted with the game significantly more than the other participants. As the study progressed, Sora became more interactive with the game.

Before attempting a puzzle, Ryu tended to identify what the problem was asking. After he solved the puzzle, he often explained how he came up with the solution or why his solution was right. The other participants did explain their solutions occasionally, but it was not something they consistently as did Ryu.

What was surprising was that Sora and Kairi both indicated that they had been playing video games for more than ten years and rated themselves as moderately to very good. Those self-identified characteristics do not appear to be supported by the think-aloud sessions. They very rarely exhibited the same game behaviors or cognitive

processes as Ryu. Kairi and Sora did not explore the game nor did they interact with the games nearly as much as Ryu. Kairi and Sora may not be exhibiting the same game playing behaviors as Ryu because of the different types of games they may play. These different game types may require different behaviors and skill sets then found in PLCV and PLDB.

*What game behaviors observed in successful game play are successful in improving science reasoning skills?*

Because overall, the study did not show improvement in science reasoning skills, it is not clear what game behaviors might be successful in improving science reasoning skills. Two possible game behaviors may actually help with reasoning. For many of the puzzles, the participants would use paper and work out the puzzle or would rotate the DS to enable them to see the puzzle from a different perspective. These two behaviors may help player slow down their thinking and work through the puzzle more effectively.

Another possible game behavior, self-reflection and other metacognitive behaviors, might help improve science reasoning skills with appropriate scaffolding. Many times the participants would realize they would be doing the wrong thing or did not understand what to do. These instances could be opportunities to help players use more productive strategies or even recognize that there could be a different way to reason out the puzzle.

More specific research is necessary to clearly determine what game behaviors of players could improve science reasoning.

## Other Findings

### How is success defined?

In terms of the problem-solving video games, being successful at solving the puzzle means you are able to continue to go forward in the game. The game does not care how the puzzle or problem is solved; as long as it is solved. All of the participants in the study took advantage of this fact throughout the study. All of the participants used hints from the game itself. Participants used random guessing, especially on puzzles where there were a limited number of possible answers. In a few instances, the participants needed assistance from the researcher to solve the puzzle during the think-aloud protocol. When a participant was working on a puzzle in the problem-solving video game outside of the think-aloud protocol and became stuck, all except for Lilo went online to find a solution. Participants also asked friends for help when stuck. In terms of completing the game, all of the participants were successful.

In terms of learning, how successful were the participants? That depends on the participant and what was learned. For example, Kairi learned early on that the sun rose in the east. Ryu started to realize that he could not attack every problem using algebra and geometry. Sora began to engage in metacognitive processes.

For the problem-solving video games to be useful in the educational setting, it is not just about getting the puzzle or problem correct or learning a content fact. The problem-solving video game should help students have a learning experience, one that they can apply to other problems. Did these two problem-solving video games provide those experiences? That remains to be seen. It seems clear from this study that the potential to create these learning experiences exists with these games. Some puzzles

contained within the game do not create these learning experiences. For instance DB 61 is essentially a trick and was frustrating for participants who did not see the trick. Other than illustrating the use of lateral thinking, DB 61 does not provide a significant, positive learning experience for the player. Other puzzles do have the potential to provide a significant, positive learning experience. Many of the puzzles that require mathematical reasoning have that potential. A possible example is CV 99: 33333! Players are told that two large numbers, consisting of the numbers 1 through 9, when subtracted will give you 33,333. The player needs to determine what the two large numbers are. In this puzzle, the player needs to understand the process of subtracting with borrowing and using a working backwards strategy. If this puzzle is scaffolded well, it could create a significant learning experience.

### **Scaffolding.**

The participants in this study played the problem-solving video games on their own with little to no assistance or discussion with the researcher. Would the results have been different if there was front-loading before the participant started a puzzle and if there was discussion after the puzzle was solved. Previous research, such as Kiili (2007), suggests the importance of discussion in problem-solving to ensure that the learning objectives were met and the correct conclusions were drawn from the problem. At different points during the think-aloud, participants seemed to want to discuss the different puzzles with someone, especially when they had difficulty or did not understand the solution. Perhaps being able to discuss the puzzles would have extended or increased the learning experience.

Both Professor Layton games provided a form of scaffolding through hints. All of the participants liked the availability of hints, but were often frustrated with the hints given. Nearly always, the first hint is a restating of the puzzle in some way. This frustrated the participants nearly every time and they felt the first hint was useless. Depending on the puzzle and the participant, the second hint may or may not have been useful. Sometimes it was a reminder not to approach a problem a certain way, it would say put this piece or number in this spot or the answer is not this option. Many times the third hint would essentially solve the problem for the player. This caused some frustration for the participants. Ryu seemed not to like it when the problem was solved for him. Other participants wondered why the third hint could not have been an earlier hint. None of the participants were happy when the hints were less than useful in their opinion. When the problem-solving video games have scaffolding, it needs to be of the kind that helps.

Sun, Wang, and Chan (2011) examined the impact of scaffolding in games on problem-solving behaviors. They found that players were able to solve a higher level of puzzle in the game with scaffolding and reduced the frustration level of the players when they reached an impasse. However, the players showed an increasing reliance on scaffolding tools and made fewer moves unassisted (Sun, Wang, & Chan, 2011). This result was seen in this study. For example, Kairi would frequently access all of the hints even if she did not need them. Perhaps a solution to this is to not allow more hints to unlock or be accessed until a certain amount of tries have been attempted or a certain length of time has passed.

### **Situating the Results in the Literature**

How do the results of this study compare to the results found in the broader literature? Overall, the results are similar to what has been previously noted in the literature. Green and McNeese (2007) propose using games to allow students to practice various cognitive skills and practices. Henderson (2002), Pillay (2003) and Blumberg, Rosenthal, and Randall (2008) all found that their participants used various cognitive strategies and processes while playing video games. The participants in this study used various cognitive strategies and processes while attempting to solve the various puzzles.

Dempsey et al. (1996) and Kiili (2007) both discuss the use of trial and error as a strategy when playing games. Dempsey et al (1996) notes that even when students realized that trial and error was not the most effective strategy, they used it anyway until it failed. This was seen in this study as well. The most common cognitive strategy or process seen was trial and error and all participants used it. Some of the participants, like Sora, came to realize that it was not the best strategy to solve the puzzles, but were unable to devise a different way to solve the puzzle.

Bitner (1991), Thorton and Fuller (1981), and English (2005) all discuss how students have difficulty recognizing certain types of problems and using the most appropriate method to solve the problem. This was clearly seen in the study as participants tended to use trial and error, guessing, or simpler mathematical reasoning to solve the different puzzles. As English (2005) discusses, the participants did not recognize what kind of strategies they needed to use to solve the puzzles more effectively. Bitner (1991) discusses how students have difficulty with problems that

require inferences. Again, this was seen in this study. Participants could not make the needed inferences that would help them solve the various puzzles.

Lee et al. (2004) discuss how games can be an avenue for students to practice various skills and strategies, simply because games allow students to have more exposure to a wider variety of problems as well as increasing the number of problems available to practice. Over the course of the study, participants played around 200 different puzzles to complete the two games, giving them exposure to multiple types of problems and different chances to practice the different cognitive skills needed.

### **Limitations**

The small number of participants is a significant limitation. It is difficult to draw generalizations for larger populations based on a sample size of five. Because of the small sample and reliability, the conclusions that have been drawn should not be applied to other situations. A different group of participants may very well give different results. Additionally, because all but one of the participants were education majors, the results might be different for different majors. Perhaps if all of the participants been science majors, the results might have differed dramatically. An in-depth case study of one or two participants may have also given a different perspective on the results.

### **Assessments.**

Another major limitation to the study was the assessments used to determine science and spatial reasoning. Assessments for science reasoning are not common and those that are available have some serious flaws that impact their validity and reliability, such as whether or not the test actually measures science reasoning. At the time of the study, there was no science reasoning assessment available that aligned with the science

reasoning skills used in the problem-solving video game and was also valid and reliable. Using the analytical reasoning portion of the GRE for the SRA turned out not to be the best decision for a variety of reasons, namely degree of difficulty and validity as the different sections appeared to significantly vary in difficulty. Although, given the lack of science reasoning assessments, there was not much choice. Additionally, the problems on the SRA were highly verbally orientated and without any graphics, but the problems in the games often contained a visual component. The verbal skills of the participants could have had an impact on how well they did on the SRA. Finally, the participants complained about the assessments claiming they were too hard and too confusing, which may have impacted their motivation on future assessment science reasoning.

Although the PSVT is a frequently used assessment of spatial reasoning, there is only one form of the test. Repeated administrations of the assessment in a short amount of time may introduce practice effects. In other words, the student taking the PSVT may remember what they did on an earlier administration of the assessment instead of working the problem out again. The time between administrations averaged about 2 months for each participant.

### **Think-aloud protocols.**

The main source of data for this study came from repeated think-aloud protocols. As discussed in previous literature about think-aloud protocols, there are some significant limitations. First and foremost, the participants in the study would stop verbalizing their thinking at different points while solving the puzzles and would have to be prompted to verbalize. At times when the participants were quiet, it was fairly obvious from their body language that they were engaged in some kind of thought but they were not



verbalizing those thoughts. Those verbalizations may have contained science reasoning but since they were never verbalized no conclusions can be drawn.

Another issue is the speed of thought. This was actually a significant problem with Ryu. He would see a problem and instantly solve it. He would then realize he had not verbalized what he had done to solve the puzzle and would proceed to explain what he had just done. This is not the same as verbalizing while solving the problem. A final issue is whether or not the participants were aware of what they were actually thinking in order to be able to verbalize those thoughts. Over and over, participants would execute a move but not be able to explain why other than it is what they thought they should have done. The participants may have been using science reasoning, but were unable to recognize their thinking as such.

### **Games.**

A final limitation to the study is the problem-solving video games themselves. Although the problem-solving video games could be solved using science reasoning skills, they did not necessarily have to be solved in that manner. The point of the game as designed is to finish the puzzles and solve the mystery, not to practice science reasoning. Furthermore, the problem-solving video games chosen for this study, PLCV and PLDB, did not actually have a significant amount of science content. A problem-solving video game that had a significant amount of science content might have produced different results.

### **Implications for Future Game Design**

What implications do the results of this study potentially have for the design of future video games that could be used to improve science reasoning or any intellectual

skill? There are four potential areas where the results from this research could be applied.

The first area involves the hints available to the player during the game. All of the participants liked having hints available, especially when stuck; however, the hints in PLCV and PLDB were not helpful or in some cases, too helpful by giving the answer. Modifying the hint structure to encourage learning would be beneficial. What could these modifications potentially look like? One modification could be to have puzzles refer back to similar puzzles that were successfully solved earlier in the game. There are many puzzles in PLCV and PLDB that are simply variations of a theme: route puzzles, age puzzles, and moving pieces puzzles. If a player became stuck, the first hint could refer back to an earlier, similar puzzle and ask the player to recall what process was used to solve that puzzle and how it could be adapted to the current puzzle context. Another potential modification could be to suggest a possible strategy or reasoning skill to use. For example, on CV 96, a hint could ask the player if they had tried to solve the puzzle using a proportion. The next hint in the sequence would then help the player set up the proportion correctly. It might also be possible to make the hints “smart” or adaptable to the mistakes the player is making. Similar smart hints have been developed by Carnegie Mellon for their Cognitive Tutor for Math, which has a database of all the potential mistakes by students and gives hints based on matching the mistake made by the student with one in the database.

Related to this would be to have the puzzles gradually increase in difficulty. PLCV and PLDB sometimes do this and sometimes do not. In many cases, there are certain puzzles that reappear in a more complicated manner later in the game. For example, DB 101 through 104 are all the same type of puzzle, marble solitaire. The setup

of each one gets more complicated though, with more possible moves and different configurations. It would be possible to have the puzzles increase in difficulty or complexity throughout the game. The participants were asked in the interviews if they thought the game was getting easier, harder or was about the same to solve the different puzzles. Overall, they responded the difficulty level was about the same, mostly because the puzzles were so varied. It would be possible to keep the same variety of puzzles but gradually increase the difficulty as the game progressed. This would keep the player challenged as well as giving them an opportunity to practice and then apply what they learned in an earlier puzzle.

Another possible implication for future game design is to build in a way to slow the player down. In many instances during the study, the participants would just click through the text without reading it because they were in a hurry to get to the next game task. Slowing the player down in the game would allow for more reflection and would give time for the knowledge acquired from solving a puzzle to move into long-memory.

One major problem, in terms of learning, was the prevalence of guessing and trial and error strategies and processes. While trial and error may be the most effective and efficient strategy in certain types of games such as action and adventure games, it is not the most effective strategy for learning. There should be some way for the game to detect if a player is guessing. If the game determines that the player is guessing, the solution explanation should give more detailed information to explain to the player how to solve the puzzle without guessing. Furthermore, the player should not be able to progress in the game without solving a similar puzzle without guessing. Also, there should be a

minimum time spent on a puzzle to prevent students from simply searching the Internet for the solution.

### **Future Research**

Given the limitations of the study, it would seem a profitable direction for future research would be to repeat the study while focusing on decreasing one or more of the limitations, such as a larger sample or a more varied sample. A larger sample would allow stronger conclusions to be drawn and, with a large enough sample, a statistical analysis and even modeling could be carried out to examine relationships or to predict which students would benefit most from playing video games. Using a more varied sample could allow for more comparison and contrasting between participants and could lead to different conclusions being drawn. Either one of these would add to the increasing game research literature.

Related to increasing the sample size or varying the sample would be to include lower level reasoners in the sample. At the beginning of the study, it was decided not to recruit students who scored very low on the initial science reasoning assessment as it was thought that the problem-solving video games would not have any impact on their science reasoning skills. It is possible that low-level reasoners would benefit the most from the game playing, given that it would allow them to practice reasoning. If guided reflection were integrated into the game playing process, it is possible that low-level reasoners might benefit the most from playing problem-solving video games.

One area that was not examined in depth but was briefly touched upon was the issue of transfer. How do game players transfer their knowledge to the game and from the game? Ryu clearly tried to use his previous knowledge to solve many of the different

problems but often had a difficult time applying the knowledge correctly. Rarely did the other participants make explicit references to their previous knowledge. They seemed unable to transfer that knowledge to the game and vice versa. One question that was not examined was the ability of players to take what they had learned while playing and apply it real-world situations. The participants were asked in the interviews if they had learned anything that could be used outside of the game and most of them could not identify any situation except for reading the directions or trying to think creatively. Actual transfer was not examined. This would be a direction for future research.

An additional direction for future research would be to increase the length of time of the study. If players had more opportunities for practice, their skills might improve. It would also give more opportunities to establish transfer.

Many times the participants became stuck while playing. Sometimes, they were able to become unstuck by working through the puzzle but in other cases, they would become more stuck and unable to solve the puzzle. At what point in the problem-solving process did the participants become stuck? How did they get unstuck? How did the puzzles that they became permanently stuck on contrast with those puzzles they were eventually able to work out? What kind of scaffolding is potentially useful to help players become unstuck? Additionally, it would be beneficial to study how long it takes before a player became stuck and then frustrated and completely unable to solve the puzzle. At various points during the think-aloud protocol, participants became so frustrated and so stuck that they were unable to solve the problem. Essentially, their learning stopped because they were so frustrated. The key would be to find out where

this tipping point is as some frustration is good for learning but too much frustration prevents learning.

Another possible direction for future research would be to have participants play the problem-solving video games but integrate more structured opportunities for discussion and reflection. Kiili (2007) supports the integration of reflection in the gaming process. Discussing different ways to solve the puzzles as well as reflecting on how the puzzles were solved could make a significant impact in the long term reasoning of the participants.

The results did show a possible, slight increase in spatial reasoning, which as discussed in the literature, is an aspect of science reasoning, with many concepts in science require spatial reasoning. It would be interesting to conduct a study where the puzzles required both spatial reasoning and hypothetical-deductive reasoning. The spatial reasoning could then function as a scaffold or a bridge to the hypothetical-deductive reasoning, thereby improving science reasoning. It may also be effective to make the hypothetical-deductive reasoning problems more visually or spatially orientated, again to provide that scaffold. Previous research, such as Piburn (1980), supports this idea possibility.

Finally, the focus of this study was on what the participants said. While playing the video games, the participants often would gesture and would work out potential solutions on paper. It would be an interesting further study to examine the actions of the participant as the puzzles were worked out using a method such as multimodal discourse analysis. It would be interesting to compare the participants in terms of gestures and when they gestured. For example, Ryu would often pretend his hand was whatever

object and try to rotate his hand in such a way to represent how he needed to move the object. Looking at what was written out could potentially give insight as to what the participant is thinking, even when not verbalizing thoughts. It would also be interesting to look at how they represent the puzzle from the video game on paper. Do they redraw the image, do they use tables, or what do they do on paper that they cannot do within the game? How do the actions the participants engage in assist them in solving the various puzzles?

### **Conclusion**

Over the course of six months, five participants of different reasoning levels and video game playing ability played two problem solving video games to examine the potential impact of the games on science reasoning skills. Unfortunately, the use of problem-solving video games did not appear to improve the science reasoning skills of the study participants. Most participants preferred to use trial and error to solve the puzzles instead of more formal reasoning. Because they were successful at solving the puzzles with trial and error, there was no need for them to use alternative strategies and processes. There were significant differences between the expert reasoner, Ryu, and the rest of the participants in terms of cognitive skills used, as Ryu used more formal reasoning skills or used trial and error in a methodical way to solve the puzzles. Although for this study, the research hypotheses were not supported, problem solving video games have potential and need further examination and study.

## REFERENCES

- ACT (2007). *The ACT technical manual*. Retrieved April 20, 2010 from [http://www.act.org/aap/pdf/ACT\\_Technical\\_Manual.pdf](http://www.act.org/aap/pdf/ACT_Technical_Manual.pdf)
- Ackerman, P. L., & Kanfer, R. (2009). Test length and cognitive fatigue: An empirical examination of effects on performance and test-taker reactions. *Journal of Experimental Psychology: Applied*, 15(2), 163-181. doi: 10.1037/a0015719
- Aldrich, C. (2005). *Learning by doing: The essential guide to simulations, computer games, and pedagogy in e-learning and other educational experiences*. San Francisco: Pfeiffer.
- Alkan, S., & Cagiltay, K. (2007). Studying computer game learning experiences through eye tracking. *British Journal of Educational Technology*, 38(3), 538-542. doi: 10.1111/j.1467-8535.2007.00721.x
- Amory, A., Naicker, K., Vincent, J., Adams, C. (1999). The use of computer games as an educational tool: Identification of appropriate game types and elements. *British Journal of Educational Technology*, 30(4), 311-324.
- Apperly, T. H. (2006). Genre and game studies: Toward a critical approach to video game genres. *Simulation Gaming*, 37(1), 6-23.
- Bart, W. M. (1972). Construction and validation of formal reasoning instruments. *Psychological Reports*, 30, 663-670.
- Bart, W. M. & Schleisman, K. E. (1988). Testing formal reasoning. *Applied Measurement in Education*, 1(2), 189-202.
- Bloom, B. S. (1956). *Taxonomy of educational objectives book 1: Cognitive Domain*. New York: Longman.



- Bitner, B. L. (1991). Formal operational reasoning modes: Predictors of critical thinking abilities and grades assigned by teachers in science and mathematics for students in grades nine through twelve. *Journal of Research in Science Teaching*, 28, 265-274.
- Bitner-Corvin, B. L. (1987, April). *The GALT: A measure of logical thinking ability of 7<sup>th</sup> through 12<sup>th</sup> grade students*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Washington, D. C. Retrieved from ERIC database. (ED293717).
- Blumberg, F. C., Rosenthal, S. F., & Randall, J. D. (2008). Impasse-driven learning in the context of video games. *Computers in Human Behavior*, 24(4), 1530-1541. doi:10.1016/j.chb.2007.05.010
- Carr, N. (2011). *The shallows: What the internet is doing to our brains*. New York: W. W. Norton & Company.
- Casey, B. M., Andrews, N., Schindler, H., Kersh, J. E., Samper, A., & Copley, J. (2008). The development of spatial skills through interventions involving block building activities. *Cognition and Instruction*, 26(3), 269-309. doi: 10.1080/07370000802177177
- Cavanagh, S. (2008). Frustrations give rise to new push for science literacy. *Education Week*, 27(26), 12.
- Chalifour, C. L., & Powers, D. E. (1988). The relationship of content characteristics of GRE analytical reasoning items to their difficulties and discriminations. *Journal of educational measurement*, 26(2), 120-132. doi: 10.1111/j.1745-3984.1989.tb00323.x

- Clark, D.B., Nelson, B. C., Chang, H., Martinez-Gaza, M., Slack, K., & D'Angelo, C. M. (2011). Exploring Newtonian mechanics in a conceptually-integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United States. *Computers and Education, 57*(3).
- Cohn, S. J., & Jaeger, R, M. (1985). [Review of the test Graduate Record Exam – General Test]. In *The ninth mental measurements yearbook*. Retrieved from EBSCO Mental Measurements Yearbook database.
- Colleta, V. P., & Philips, J. A. (2005). Interpreting FCI scores: Normalized gain, preinstruction scores, and scientific reasoning ability. *American Journal of Physics, 73*, 1172.
- Collings, J. N. (1985). Scientific thinking through the development of formal operations; Training in the cognitive restructuring aspect of field-independence. *Research in Science & Technological Education, 3*(2), 145-152
- Collings, J. N. (1994). Some fundamental questions about scientific thinking. *Research in Science & Technological Education, 12*(2), 161.
- Crawford, C. (2011). *The Art Of Computer Game Design: Reflections Of A Master Game Designer* [Kindle version]. Retrieved from Amazon.com (Original work published 1984).
- Cruickshank, D. R., & Tefler, R. (1980). Classroom games and simulations. *Theory into Practice, 19*(1), 75-80.
- Culatta, R. (2011). Lateral thinking. Retrieved from <http://www.instructionaldesign.org/theories/lateral-thinking.html>
- Dempsey, J. V., Lucassen, B. A., Haynes, L. L., & Casey, M. S. *Instructional*

- applications of computer games*. Retrieved from ERIC Database. (ED394500).
- Dewey, J. (1910). Science as subject-matter and as method. *Science*, 31(787), 121-127.
- Djaouti, D., Alvarez, J., Jessel, J., & Methel, G. (2007). *Towards a classification of video games*. Paper presented at the meeting of AISB'07, Scotland. Retrieved from <http://www.gameclassification.com/EN/about/article.html>
- Dondlinger, M. J. (2007). Educational video game design: A review of the literature. *Journal of Applied Educational Technology*, 4(1), 21-31.
- Dorval, M., & Pepin, M. (1986). The effect of playing a video game on a measure of spatial visualization. *Perceptual and Motor Skills*, 62(1), 159-162.
- Dunbar, K., & Fugelsang, J. (2005). Scientific thinking and reasoning. In K. J. Holyoak, & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 705-725). Cambridge: Cambridge University Press.
- Ellington, H., Addinall, E., & Percival, F. (1981). *Games and Simulations in Science Education*. NY: Nichols.
- English, L. D. (2005). Combinatorics and the development of children's combinatorial reasoning. In G. A. Jones (Eds.), *Exploring probability in school: Challenges for teaching and learning* (pp. 121-141). NY: Springer.
- Enyeart, M. A., Baker, D., & Van Harlingen, D. (1980). Correlation of inductive and deductive logical reasoning to college physics achievement. *Journal of Research in Science Teaching*, 17(3), 263-267.
- Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as Data. *Psychological Review*, 87(3), 215-251.
- Etkina, E., Karelina, A., & Villasenor, M. R. (2007). Studying transfer of scientific

- reasoning abilities. In L. McCullough, L. Hsu, and P. Heron (Eds.), *2006 Physics Education Research Conference: Vol. 883*
- Fisch, K., & McLeod, S. (2007, June 22). *Shift happens*. Retrieved on July 15, 2009, from <http://shifthappens.wikispaces.com/>
- Fisch, S. M. 2005. Making educational computer games "educational". In *Proceedings of the 2005 Conference on interaction Design and Children* (Boulder, Colorado, June 08 - 10, 2005), 56-61. doi:10.1145/1109540.1109548
- Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York: Palgrave MacMillan.
- Gredler, M. E. (2004). Games and simulations and their relationship to learning. In D. H. Jonassen (Eds.), *Handbook of research for educational communications and technology*. Mahwah, NJ: Lawrence Erlbaum.
- Green, M., & McNeese, M. N. (2007). Using edutainment software to enhance online learning. *International Journal on E-Learning*, 6(1).
- Gros, B. (2007). Digital games in education: The design of games-based learning environments. *Journal of Research on Technology in Education*, 40(1), 23-38.
- Guay, R. B. (1977). *Purdue Spatial Visualization Test*. West Lafayette, IN: Purdue Research Foundation.
- Halpern, D. F., & Collaer, M. L. (2005). Sex differences in visuospatial abilities: More than meets the eye. In P. Shah and A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 177-214). Cambridge: Cambridge University Press.
- Hatcher, J. W., Jr. (1990). Using riddles to introduce the process and experience of scientific thinking. *Teaching of Psychology*, 17(2), 123-124.

- Hegarty, M., & Waller, D. A. (2005). Individual differences in spatial abilities. In P. Shah and A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 121-169). Cambridge: Cambridge University Press.
- Heinich, R., Molenda, M., Russell, J. D., & Smaldino, S. E. (2002). *Instructional media and technologies for learning*. (7<sup>th</sup> Ed.). Upper Saddle River, NJ: Merrill.
- Henderson, L. (2002). Playing video games and cognitive effects: Teenagers' thinking skills and strategies. In P. Barker & S. Rebelsky (Eds.), *Proceedings of the world conference on educational multimedia and telecommunications* (pp. 759-760). Chesapeake, VA: AACE
- Hogle, J. G. (1996). *Considering games as cognitive tools: In search of effective "edutainment."* Retrieved from ERIC database. (ED425737).
- Hong, J., Hwang, M., Lu, C., Cheng, C., Lee, Y., & Lin, C. (2009). Playfulness-based design in educational games: A perspective on an evolutionary contest game. *Interactive Learning Environments*, 17(1), 15-35.
- Irons, J. L., Remington, R. W., & McLean, J. P. (2011). Not so fast: Rethinking the effects of action video games on attentional capacity. *Australian Journal of Psychology*, 63, 224-231.
- Jenkins, H. (2002). Game Theory. How should we teach kids Newtonian physics? Simple. Play computer games. Retrieved from <http://www.technologyreview.com/energy/12784/?a=f>
- Kiili, K. (2007). Foundation for problem-based gaming. *British Journal of Educational Technology*, 38(3), 394-404.
- Kirriemuir, J., & McFarlane, A. (2004). *Literature review in games and learning* (Report

8). Retrieved from Futurelab website:

[http://archive.futurelab.org.uk/resources/documents/lit\\_reviews/Games\\_Review.pdf](http://archive.futurelab.org.uk/resources/documents/lit_reviews/Games_Review.pdf)

Koster, R. (2005). *A theory of fun for game design*. Scottsdale AZ: Polygraph Press.

Lajoie, S. P. (2003). Individual differences in spatial ability: Developing technologies to increase strategy awareness and skills. *Educational Psychologist*, 38(2), 115-125.

Lawson, A. E. (1985). A review of research on formal reasoning and science teaching. *Journal of Research in Science Teaching*, 22, 569-617.

Lawson, A. E. (1993). At what levels of education is the teaching of thinking effective? *Theory into Practice*, 32(3), 170-178.

Lawson, A. E. (1995). *Science teaching and the development of thinking*. Belmont, CA: Wadsworth.

Lawson, A. E. (2000). The Generality of Hypothetico-deductive reasoning: Making scientific thinking explicit. *The American Biology Teacher*, 62(7), 482-495.

Lawson, A. E. (2004). Reasoning and brain function. In J. P. Leighton & R. J. Sternberg (Eds.), *The nature of reasoning* (pp. 12-48). Cambridge: Cambridge University Press.

Lawson, A. E. (2005). What is the role of induction and deduction in reasoning and scientific inquiry? *Journal of Research in Science Teaching*, 42(6), 716-740.

Lee J., Luchini, K., Michael, B., Norris, C., & Soloway, E. (2004). More than just fun and games: Assessing the value of educational video games in the classroom. In *Proceedings from Conference on Human Factors in Computing Systems* (pp. 1375 - 1378).

Leighton, J. P. (2004). Defining and describing reason. In J. P. Leighton & R. J. Sternberg (Eds.), *The nature of reasoning* (pp. 3-11). Cambridge: Cambridge

University Press.

- Lord, T. R. (1985). Enhancing the visuo-spatial aptitude of students. *Journal of Research in Science Teaching*, 22(5), 395-405
- Lord, T. R., & Rupert, J. L. (1995). Visual-spatial aptitude in elementary education majors in science and math tracks. *Journal of Elementary Science Education*, 7(2), 47-58.
- Mayer, R. E. (2005). Multimedia learning: guiding visuospatial thinking with instructional animation. In P. Shah and A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 477-508). Cambridge: Cambridge University Press.
- McCann, S. (2009). Game genres demystified. *Library Journal*, 134(1), 56.
- McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin*, 86(5), 889-918.
- McGonigal, J. (2011). *Reality is broken: Why games make us better and how they can change the world*. London: Penguin.
- Moreno, R. & Mayer, R. E. (2005). Role of guidance, reflection, and interactivity in an agent-based multimedia game. *Journal of Educational Psychology*, 97, 117-128.
- Moses, B. E. (1980). *The relationship between visual thinking tasks and problem-solving performance*. Retrieved from ERIC database. (ED187734).
- National Research Council. (1996). *National science education standards*. Washington, D. C.: National Academy Press
- Nelson, R. A., & Strachan, I. (2009). Action and puzzle video games prime different

- speed/accuracy trade offs. *Perception*, 38, 1678-1687.
- Nickerson, R. S. (1991). Modes and models of informal reasoning. In J. F. Voss, D. N. Perkins, & J. W. Segal (Eds.), *Informal reasoning and education* (pp). Hillsdale, NJ: Erlbaum.
- O'Neill, D. K., & Polman, J. L. (2004). Why educate "little scientists?" Examining the potential of practice-based scientific literacy. *Journal of Research in Science Teaching*, 41(3), 234-266.
- Okan, Z. (2003). Edutainment: Is learning at risk? *British Journal of Educational Technology*, 34(3), 255-264.
- Papert, S. (1998). Does easy do it? Children, games and learning. *Game Developer*, 5(6), 88-89.
- Partnership for 21<sup>st</sup> Century Skills. (2011). *Defining 21<sup>st</sup> century skills*. Retrieved from Assessment and Teaching of 21<sup>st</sup> Century Skills website:  
<http://atc21s.org/GetAssets.axd?FilePath=/Assets/Files/6cb2492b-f903-42c4-a408-cc6107a046ab.pdf>
- Patton, M. Q. (2002). *Qualitative research and evaluation methods*. Thousand Oaks, CA: Sage.
- Piburn, M. (1980). Spatial Reasoning as a Correlate of Formal Thought and Science Achievement for New Zealand Students. *Journal of Research in Science Teaching*, 17(5), 443-448.
- Pillay, H. (2003). An investigation of cognitive processes engaged in by recreational computer game players: Implications for skills of the future. *Journal of Research on Technology in Education*, 34(3), 336-350.



- Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill.
- Professor Layton and the Curious Village [Game]. (2008). Japan: Level-5.
- Professor Layton and the Diabolical Box [Game]. (2009). Japan: Level-5.
- Pulman, A. (2007). Can a handheld device be used as an effective assistive technology tool? Retrieved from [http://www.techdis.ac.uk/index.php?p=2\\_1\\_7\\_9](http://www.techdis.ac.uk/index.php?p=2_1_7_9)
- Randel, J. M., Morris, B. A., Wetzel, C. D., & Whitehall, B. V. (1992). The effectiveness of games for educational purposes: A review of recent research. *Simulation & Gaming*, 23(3), 261-276.
- Rice, J. W. (2007). Assessing higher order thinking in video games. *Journal of Technology and Teacher Education*, 15(1), 87-100.
- Rifkin, T. & Georgakakos, J. H. (1996). *Reasoning ability of community college students*. Retrieved from ERIC database. (ED393505)
- Ritchhart, R., & Perkins, D. N. (2005). Learning to think: The challenges of teaching thinking. In K. J. Holyoak, & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 775-802). Cambridge: Cambridge University Press.
- Roberge, J. J. (1976). Developmental analyses of two formal operational structures: Combinatorial thinking and conditional reasoning. *Developmental Psychology*, 12(6), 563-564.
- Robertson, S. I. (1999). *Types of thinking*. New York: Routledge.
- Saldaña, J. (2009). *The coding manual for qualitative researchers*. London: Sage.
- Sandford, R., Ulicsak, M., Facer, K., & Rudd, T. (2007) Teaching with games: Using commercial off the shelf computer games in education, Bristol: Futurelab - for

Electronic Arts. Retrieved from

[http://www.futurelab.org.uk/resources/documents/project\\_reports/teaching\\_with\\_games/TWG\\_report.pdf](http://www.futurelab.org.uk/resources/documents/project_reports/teaching_with_games/TWG_report.pdf)

- Sanz de Acedo Lizarraga, M. L., Sanz de Acedo Baquendano, M. T., Mangado, T. G., and Cardelle-Elawar, M. (2009). Enhancement of reasoning skills: effects of two intervention methods. *Thinking skills and creativity*, 4, 30-43.
- Shaffer, D. W. (2006). *How computer games help children learn*. New York: Palgrave.
- Sorby, S. A., Leopold, C., & Górski, R. (1999). Cross-cultural comparisons of gender differences in the spatial skills of engineering students. *Journal of Women and Minorities in Science and Engineering*, 5, 279-291.
- Squire, K. D., & Jan, M. (2007). Mad City Mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology*, 16(1).
- Squire, K., Barnett, M., Grant, J. M., & Higginbotham, T. (2004). Electromagnetism Supercharged! Learning physics with digital simulation games. In Kafai, Y. B., Sandoval, W. A., Enyedy, N., Nixon, A. S., & Herrera, F., (Eds.), *Proceedings of the Sixth International Conference of the Learning Sciences*, pp. 513-520. Mahwah, NJ: Lawrence Erlbaum.
- Stadler, M. A. (1998). Demonstrating scientific reasoning. *Teaching of Psychology*, 25(3), 205-206
- Stuessy, C. L. (1989). Path analysis: a model for the development of scientific reasoning abilities in adolescents. *Journal of Research in Science Teaching*, 26, 41-53.
- Sun, C., Wang, D., & Chan, H. (2011). How digital scaffolds in games direct problem-

- solving behaviors. *Computers & Education*, 57, 2118-2125.
- Tennyson, R. D. & Jorczak, R. D. (2008). A conceptual framework for the empirical study of instructional games. In H. F. O'Neil, & R. S. Perez (Eds.), *Computer games and team and individual learning* (pp. 3-20). Oxford: Elsevier.
- Terlecki, M.S. & Newcombe, N.S. (2005). How important is the digital divide? The relation of computer and videogame usage to gender differences in mental rotation ability. *Sex Roles*, 53, 433-441. Retrieved from [http://silccenter.org/resource-info/tests\\_index.html#Video](http://silccenter.org/resource-info/tests_index.html#Video)
- Thornton, M. C., & Fuller, R. G. (1981). How do college students solve proportion problems? *Journal of Research in Science Teaching*, 18(4), 335-340.
- Tornkvist, S. (1981). Mastermind and scientific method. *Physics Education*, 16, 344-346.
- Van Eck, R. (2007). Six ideas in search of a discipline. In B. E. Shelton, & D. A. Wiley (Eds.), *The design and use of simulation computer games in education* (pp. 31-60). Rotterdam, The Netherlands: Sense.
- Van Gelder, T., & Bulka, A. (2000). *Reason!* Improving informal reasoning skills. Retrieved April 4, 2010 from <http://www.arts.unimelb.edu.au/~tgelder/papers/ACE2000.pdf>
- VanSickle, R. L. (1986). A quantitative review of research on instructional simulation gaming. *Theory and Research in Social Education*, 14, 245-264.
- Van Someren, M. W., Barnard, Y. F., & Sandberg, Y. A. C. (1994). *The think-aloud method: A practical guide to modeling cognitive processes*. London: Academic Press.

- Vass, E., Schiller, D., & Nappi, A. J. (2000). The effects of instructional intervention on improving proportional, probabilistic, and correlational reasoning skills among undergraduate education majors. *Journal of Research in Science Teaching*, 37(9), 981-995.
- Watson, W. R. (2007). *Formative research on an instructional design theory for educational games* (Doctoral dissertation). Available from ProQuest Dissertations and Theses database (UMI No. 3278250).
- Wheatley, G. H. (1990). Spatial sense and mathematics learning. *The Arithmetic Teacher*, 37(6), 10-11.
- Wilson, V. (2000). Can thinking skills be taught? Retrieved from [http://www.peopledev.co.za/library/can\\_think\\_skill\\_be\\_taught.pdf](http://www.peopledev.co.za/library/can_think_skill_be_taught.pdf)
- Wood, L. E., & Stewart, P. W. (1987). Improvement of practical reasoning skills with a computer game. *Journal of Computer-Based Instruction*, 14(2), 49-53.
- Zemke, R. (1997). When is a game not a game and a cigar just a smoke. Retrieved from <http://www.trainingforum.com/091097rz.html>
- Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental review*, 27, 172-223

**APPENDIX A: VIDEO GAME EXPERIENCE SURVEY**

Name (please print): \_\_\_\_\_


Gender (please circle one):    Male                      Female

Age: \_\_\_\_\_ Major: \_\_\_\_\_

**Directions:** Please circle the best answer for each of the following questions, or write your answer in the space marked “other”.

1. Have you ever played video games?              Yes                      No

2. Do you currently play video games?              Yes                      No

 If your answer was “No” to either question, why don’t you play video games?

- a. cost                                      d. lack of skill  
 b. not interested                      e. not allowed (parents, teachers, etc.)  
 c. not enough time                      f. other \_\_\_\_\_

**If your answer to # 1 or # 2 was “No”, answer please skip to question # 12.**

3. How long have you been playing video games?

- a. 6 months                                      d. 5-10 years  
 b. 1 year    e. 10 or more years  
 c. 2-5 years

4. How did you get started playing video games; who or what motivated you to play?

- a. self interest                                      d. advertisements (magazines, TV, newspaper)  
 b. other female/s                                      e. the internet  
 c. other male/s                                      f. other \_\_\_\_\_

5. How often (approximately) do you currently play video games?

- a. daily    d. once in 6 months  
 b. weekly    e. once a year  
 c. once a month                                      f. less than once a year or never

6. How good do you feel you are at playing video games?

- a. very good                                      c. not very skilled  
 b. moderately good                                      d. no skill

7. What consoles do you own (if any)? Please list all.

Wii	Nintendo DS	Nintendo GameBoy	Nintendo GameCube	Super Nintendo
Sony Playstation	Sony Playstation 2	Sony Playstation 3	PSP	Xbox
Sega	Atari	Only play games on Computer	Other	

8. If you do not own a console, how do you play?

- |                           |                |
|---------------------------|----------------|
| a. other friends that own | d. on my phone |
| b. online/internet        | e. handheld    |
| c. arcade                 | f. other _____ |

9. What are your Top 3 (in order) genres, or video game categories, that you enjoy to play? (Choose from the list on the last page of this questionnaire, or add your own).

- #1. \_\_\_\_\_
- #2. \_\_\_\_\_
- #3. \_\_\_\_\_

10. What are your Top 5 (in order) video games that you like to play?

- |           |           |
|-----------|-----------|
| #1. _____ | #4. _____ |
| #2. _____ | #5. _____ |
| #3. _____ |           |

11. Based on your Top 3 and Top 5, what attracts you to these games?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

12. Would you be interested in playing video games in the future?      Yes      No

14. Have you ever played the game Professor Layton and the Curious Village or Professor Layton and the Diabolical Box?

Yes      No

15. Have you ever played the game Legend of Zelda: The Phantom Hourglass?

Yes      No

16. How many math classes have you taken so far in college? \_\_\_\_\_

17. How many science classes have you taken so far in your college career? \_\_\_\_\_

**Video Game Genres (for #9):**

Action  
Fighting  
First-person shooter  
Role-playing  
Massively Multiplayer Online Games  
Simulators  
Flight  
Racing  
Sports  
Military  
Space  
Strategy  
Strategy wargames  
Real-time strategy and turn-based strategy games  
Real-time tactical and turn-based tactical  
God games  
Economic simulation games  
City-building games  
Adventure  
Arcade  
Educational  
Maze  
Music  
Pinball  
Platform  
Puzzle  
Stealth  
Survival horror  
Vehicular combat  
Fitness  
Music (like RockBand or Guitar Hero)  
Other (please specify)

## APPENDIX B: SAMPLE QUESTIONS FROM SCIENCE REASONING ASSESSMENT

### SRA #1:

1. Rule 1 of Game X provides that anyone who refuses to become a player in Game X shall at the moment of refusal be assessed a ten-point penalty in the game.  
Which of the following claims is implicit in Rule 1?
  - a. All those who agree to play Game X will achieve scores higher than the scores of those who were assessed a penalty under Rule 1.
  - b. A person can avoid a ten-point penalty by initially agreeing to become a player and then withdrawing after the game is under way.
  - c. The rules of Game X supply a procedure for determining when the game is over.
  - d. A person who refuses to play Game X cannot be declared a loser in the game.
  - e. A person can at the same time decline to play Game X and yet be a part of the game.
  
2. If your radio was made after 1972, it has a stereo feature. This statement can be deduced logically from which of the following statements?
  - a. Only if a radio was made after 1972 could it have a stereo feature.
  - b. All radios made after 1972 have a stereo feature.
  - c. Some radios made before 1972 had a stereo feature.
  - d. Some stereo features are found in radios made after 1972.
  - e. Stereo features for radios were fully developed only after 1972.

A pet store owner is setting up several fish tanks, each to contain exactly six fish so chosen from species F, G, H, I, J, K and L so that none of the fish in any given tank will fight. Fish of any of the species of the species can be placed in a tank together except for the following restrictions: --Fish of species F will fight with fish of species H, J and K. --Fish of species I will fight with the fish of species G and K. --If three or more fish of species I are in one tank, they will fight with each other. --Fish of species J will fight with fish of species L. --If a species G is to be in a tank, at least one fish of species K must also be in the tank.

3. A tank is to contain fish of exactly three different species, these species could be
  - a. F, G and I
  - b. F, I, and K
  - c. G, H, and I
  - d. H, I, and J
  - e. I, J and L



4. If there are to be exactly two species represented in a tank, and three fish of species J are to be in the tank, the other three fish in that tank could be from which of the following species?
  - a. F
  - b. B
  - c. H
  - d. I
  - e. L
  
5. If a tank is to contain fish of exactly four different species, it CANNOT contain fish of species
  - a. F
  - b. G
  - c. H
  - d. J
  - e. L
  
6. Fish of which of the following species could be put into a tank with fish of species G?
  - a. F and I
  - b. F and J
  - c. H and I
  - d. H and K
  - e. I and K

**SRA #2**

On an island there are exactly seven towns: T, U, V, W, X, Y and Z. All existing and projected roads on the island are two-way and run perfectly straight between one town and the next. All distances by road are distances from the main square of one square to the main square of another town. U is the same distance by road from T, V, and W as Y is from X and Z. The following are all of the currently existing roads and connections by road on the island: Road 1 goes from T to V via U. Road 2 goes from U directly to W. The Triangle Road goes from X to Y, From Y on to Z, and from Z back to X. Any main square reached by two roads is an interchange between them, and there are no other interchanges between roads.

1. Which of the following is a town from which exactly two other towns can be reached by road?
  - a. T
  - b. U
  - c. V
  - d. W
  - e. X
  
2. It is possible that the distance by road from X to Y is unequal to the distance by road from
  - a. T to U
  - b. U to V
  - c. U to W
  - d. X to Z
  - e. Y to Z
  
3. Which of the following is a pair of towns connected by two routes by road that have no stretch of road in common?
  - a. T and U
  - b. U and V
  - c. V and W
  - d. W and X
  - e. X and Y
  
4. If a projected road from T to Y were built, then the shortest distance by road from W to X would be the same as the shortest distance by road from Z to
  - a. T
  - b. U
  - c. V
  - d. X
  - e. Y

5. If two projected roads were built, one from T directly to Y and one from V directly to Z, then each of the following would be a complete list of the towns lying along one of the routes that a traveler going by road from U to X could select EXCEPT
- a. T, Y
  - b. T, Z
  - c. V, Z
  - d. T, Y, Z
  - e. V, Z, Y

**SRA #3**

1. M is heavier than Q, But it is lighter than R. S is heavier than Q and it is also heavier than R. U is heavier than Q and it is also heavier than R. If the statements above are true, one can conclude with certainty that T is heavier than M if one knows in addition that
  - a. S weighs the same as U weighs
  - b. S is heavier than T.
  - c. T is heavier than Q.
  - d. T is heavier than U.
  - e. U is heavier than M.
  
2. The cost of the average computer logic device is falling at the rate of 25% per year, and the cost of the average computer memory device at the rate of 40% per year. It can be concluded that if these rates remain constant for a period of 3 years, at the end of that time the cost of the average computer memory device will have declined by a greater amount than the cost of the average computer logic device. Accurate information about which of the would be the most useful in evaluating the correctness of the conclusion above?
  - a. The number of logic devices and memory devices projected to be purchased during the next 3 years.
  - b. The actual prices charged for the average computer logic device and the average computer memory device.
  - c. The compatibility of different manufacturers' logic devices and memory devices.
  - d. The relative durability of logic devices and memory devices.
  - e. The average number of logic devices and memory devices needed for an average computer system.
  
3. Earthquakes, volcanic eruptions, and unusual weather have caused many more natural disasters adversely affecting people in the past decade than in previous decades. We can conclude that the planet Earth as a natural environment has become more inhospitable and dangerous, and we should employ the weather and earth sciences to look for the causes of this trend. The conclusion drawn above is most seriously weakened if which of the following is true?
  - a. The weather and earth sciences have provided better early warning systems for natural disasters in the past decade than in previous decades.
  - b. International relief efforts for victims of natural disasters have been better organized in the past decade than in previous decades.
  - c. There are records of major earthquakes, volcanic eruptions, droughts, landslides, and floods occurring in the distant past, as well as in the recent past.
  - d. Population pressures and poverty have forced increasing numbers of people to live in areas prone to natural disasters.
  - e. There have been no changes in the past decade in people's land-use practices that could have affected the climate.

4. During the month of July in City X, the humidity was always 80 percent or higher whenever the temperature was 75 F or higher. Temperatures that month ranged from 65 F to 95 F. If the statements in the passage above are true, which of the following CANNOT be an accurate report of a temperature and humidity reading for City X in July?

- a. 77 F, 81%
- b. 76 F, 80%
- c. 75 F, 79%
- d. 74 F, 78%
- e. 73 F, 77%

5. Anyone who has owned a car knows that saving money in the short run by skimping on relatively minor repairs and routine maintenance will prove very costly in the long run. However, this basic truth is often forgotten by those who call for reduced government spending on social programs. Which of the following is NOT implied by the analogy above as a point of comparison?

- a. Money that is spent on repairs and maintenance helps to ensure the continued functioning of a car.
- b. Owners can take chances on not maintaining or repairing their cars.
- c. In order to keep operating, cars will normally need some work.
- d. The problems with a car will become worse if they are not attended to.
- e. A car will last for only a limited period of time and then must be replaced

6. If athletes want better performances, they should train at high altitudes. At higher altitudes, the body has more red blood cells per unit volume of blood than at sea level. The red blood cells transport oxygen, which will improve performance if available in greater amounts. The blood of an athlete who trains at high altitudes will transport more oxygen per unit volume of blood, improving the athlete's performance. Which of the following, if true, would be most damaging to the argument above, provided that the athlete's heart rate is the same at high and low altitudes?

- a. Scientists have found that an athlete's heart requires a period of time to adjust to working at high altitudes.
- b. Scientists have found that the body's total volume of blood declines by as much as 25% at high altitudes.
- c. Middle distance runners who train at high altitudes sometimes lose races to middle distance runners who train at sea level.
- d. The performances of athletes in competitions at altitudes have improved markedly during the past 20 years.
- e. At altitudes above 5,500 feet, middle distance runners often better their sea-level running times by several seconds.

**SRA #4**

An instructor regularly offers a six-week survey course on film genres. Each time the course is given, she covers 6 of the following 8 genres: adventure films, cinema noir, detective films, fantasy films, horror films, musical comedies, silent films and westerns. She will discuss exactly 1 genre per week according to the following conditions: Silent films are always covered, and always in the first week. Westerns and adventure films are always covered, with westerns covered in the week immediately preceding the week adventure films are covered. Musical comedies are never covered in the same course in which fantasy films are covered. If detective films are covered, they are covered after westerns are covered, with exactly 1 of the other genres covered between them. Cinema noir is not covered unless detective films are covered in one of the previous weeks.

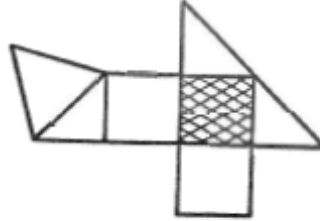
1. Which of the following is an acceptable schedule of genres for weeks one through six of the course?
  - a. Silent films, westerns, adventure films, detective films, horror films, musical comedies
  - b. Silent films, westerns, adventure films, horror films, detective films, fantasy films
  - c. Fantasy films, musical comedies, detective films, cinema noir, westerns, adventure films
  - d. Westerns, adventure films, detective films, cinema noir, musical comedies, horror films
  - e. Detective films, westerns, adventure films, horror films, fantasy films, cinema noir
  
2. If musical comedies are covered the week immediately preceding the week westerns are covered, which of the following can be true?
  - a. Adventure films are covered the second week.
  - b. Cinema noir is covered the fourth week.
  - c. Detective films are covered the third week.
  - d. Fantasy films are covered the fifth week.
  - e. Horror films are covered the sixth week.
  
3. Which of the following will never be covered in the sixth week of the course?
  - a. Cinema Noir
  - b. Fantasy Films
  - c. Horror films
  - d. Musical comedies
  - e. Westerns

A cryptanalyst must translate into letters all of the digits included in the following two lines of nine symbols each: 9 3 3 4 5 6 6 6 7 2 2 3 3 4 4 5 7 8 The cryptanalyst has already determined some of the rules governing the decoding: Each of the digits from 2 to 9 represents exactly 1 of these 8 letters: A, E, I, O, U, R, S, and T, and each letter is represented by exactly 1 of the digits. If a digit occurs more than once, it represents the same letter on each occasion. The letter T and the letter O are each represented exactly 3 times. The letter I and the letter A are each represented exactly 2 times. The letter E is represented exactly 4 times.

4. If 2 represents R and 7 represents A, then 5 must represent
  - a. I
  - b. O
  - c. S
  - d. T
  - e. U
5. Which of the following is a possible decoding of the five digit message 4 6 5 3 6?
  - a. O-T-A-E-T
  - b. O-T-E-U-T
  - c. O-O-S-E-O
  - d. T-O-I-E-T
  - e. T-O-R-E-T
6. If 9 represents a vowel, it must represent which of the following?
  - a. A
  - b. E
  - c. I
  - d. O
  - e. U
7. If 8 represents a vowel, which of the following must represent a consonant?
  - a. 2
  - b. 4
  - c. 5
  - d. 7
  - e. 9

**APPENDIX C: SAMPLE QUESTIONS FROM  
PURDUE SPATIAL VISUALIZATION TEST (PSVT)**

**1**



**A**



**B**



**C**



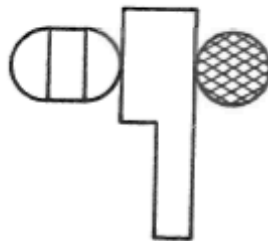
**D**



**E**



**2**



**A**



**B**



**C**



**D**



**E**





13



IS ROTATED TO



AS



IS ROTATED TO

A



B



C



D



E



14



IS ROTATED TO



AS



IS ROTATED TO

A



B



C



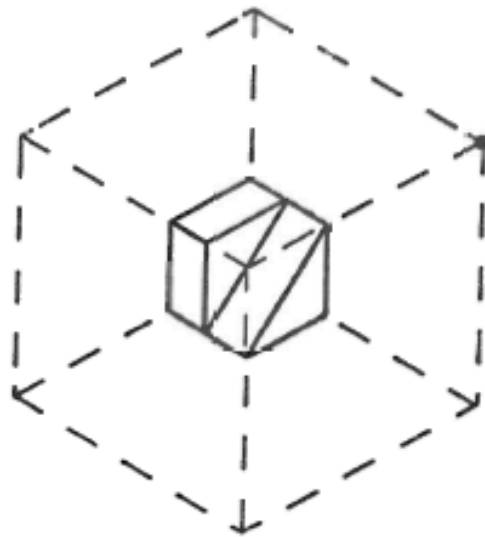
D



E



25



A



B



C



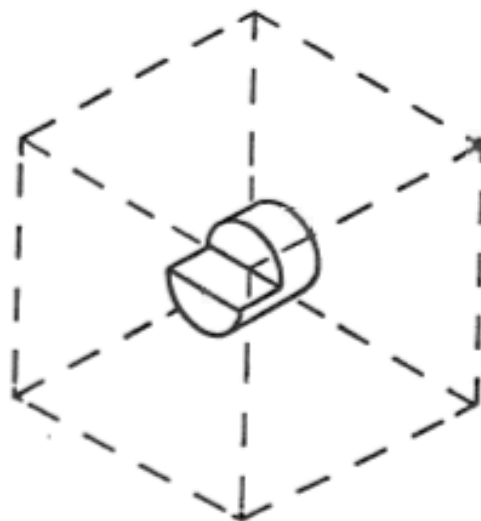
D



E



26



A



B



C





D






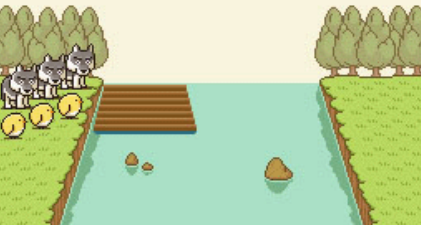
E

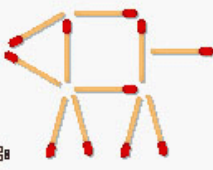



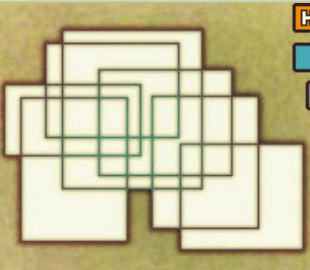
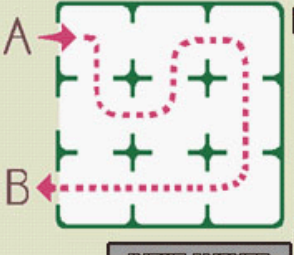
# APPENDIX D: PUZZLES PLAYED IN PROFESSOR LAYTON AND THE CURIOUS VILLAGE

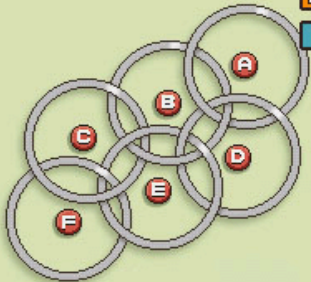

Number	Name	Screenshot	Type	Played By
1	Where's the Town	<p><b>No.001</b>    <b>10 PICARATS</b>    <b>COINS : 10</b></p> <p>"My village is on a road that leads to no other towns. I look forward to seeing you there."</p> <p>Use your stylus to draw a circle around the right village, and then touch Submit.</p> 	Spatial – Maze	Ryu, Lilo, Peach, Kairi, Sora
2	The Crank and Slot	<p><b>No.002</b>    <b>15 PICARATS</b>    <b>COINS : 10</b></p> <p>There's no way to lower the bridge and get across without inserting the crank into the correct slot!</p> <p>Choose the slot that fits the crank shown below.</p>  <p><b>TAP A SLOT'S BUTTON TO ANSWER.</b></p>	Spatial - Match	Ryu, Lilo, Peach, Kairi, Sora

3	Strange Hats	<p><b>No.003</b> 10 PICARATS COINS: 18</p> <p>These four top hats are all the same height, but the length of each brim is different. In other words, the hats are equally tall but vary in width.</p> <p>One of these four hats has a brim and height that are the same length. Which hat is it?</p>  <p>HINTS 1 2 3</p> <p>QUIT</p>	Spatial – Optical Illusion	Ryu, Lilo, Peach, Kairi,
4	Where's My House	<p><b>No.004</b> 20 PICARATS COINS: 16</p> <p>Can you find my house?</p> <p>Go out the front door of my place and turn left. At the first intersection you come across, take a right. Turn right again at the following intersection, and you'll come face-to-face with the morning sun.</p> <p>Circle my house.</p>  <p>HINTS 1 2 3</p> <p>QUIT</p> <p>CLEAR</p> <p>SUBMIT</p>	Spatial Hypothetical-deductive	Ryu, Lilo, Peach, Kairi, Sora

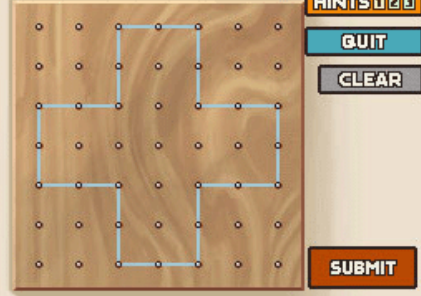
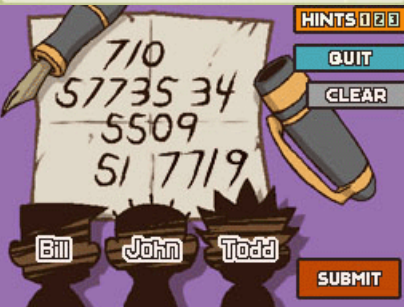
6	Light Weight	<p><b>No.006</b> 100 PICARATS COINS: 10</p> <p>Here we have eight small weights that all look the same. However, one of the weights in the group is slightly lighter than the rest.</p> <p>Using this scale two times, you can find out which of these weights is <b>lighter</b> than the rest.</p> <p>So, which weight is the <b>light</b> one?</p> <p><b>RESTART</b> <b>HINTS 1 2 3</b> <b>QUIT</b></p> 	Hypothetical-Deductive Proportional	Ryu, Lilo, Peach, Kairi, Sora
7	Wolves and Chicks	<p><b>No.007</b> 50 PICARATS COINS: 22</p> <p>Get the three wolves and three chicks seen below to the other side of the river while obeying the following conditions.</p> <ul style="list-style-type: none"> <li>-No more than two animals can ride the raft at the same time.</li> <li>-There must be at least one animal on the raft in order for it to move.</li> <li>-If more wolves than chicks stay on either side of the river, the wolves will eat the chicks, and you'll have to start over.</li> </ul> <p>You can move the raft as many times as you like, but this feat can be accomplished in as few as 11 moves.</p> <p><b>RESTART</b> <b>HINTS 1 2 3</b> <b>MOVES: 0</b> <b>QUIT</b></p> 	Logic	Ryu, Lilo, Peach, Kairi, Sora

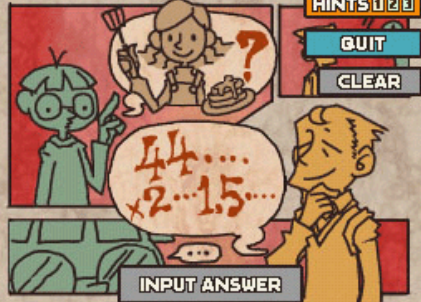
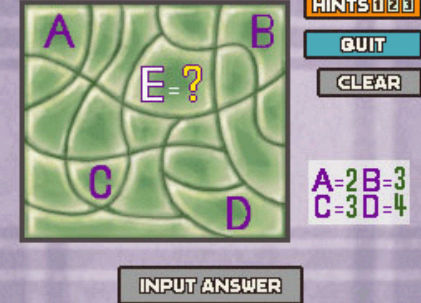
9	One Poor Pooch	<p><b>No.009 83 PICARATS COINS : 23</b></p> <p>The matches below are arranged in the shape of a dog. This poor little guy was just minding his own business when a car came barreling down the road and ran him over.</p> <p>Move two matches to change the picture so that it shows the dog after the accident.</p> <p>All puzzles are a matter of perspective, so don't assume that you'll be looking at the dog from the side by the time you're finished with this one.</p> <p><b>SUBMIT RESET HINTS 1 2 3</b></p> <p><b>QUIT</b></p>  <p>Moves Left: <b>2</b></p>	Lateral Spatial	Ryu, Peach, Kairi, Sora
12	Make a Rectangle	<p><b>No.012 30 PICARATS COINS : 103</b></p> <p>If you want to cut the piece of paper shown in Diagram 1 into two pieces and then reassemble them to form a rectangle, all you have to do is cut the paper as shown in Diagram 2.</p> <p>However, in order to assemble the pieces as shown in Diagram 2 you need to flip one of the pieces over before putting them together.</p> <p>Where should you cut the paper if you want to turn the paper in Diagram 1 into a rectangle without flipping either of your two pieces?</p> <p><b>HINTS 1 2 3</b></p> <p><b>QUIT</b></p> <p><b>CLEAR</b></p>  <p><b>SUBMIT</b></p>	Spatial	Ryu Lilo

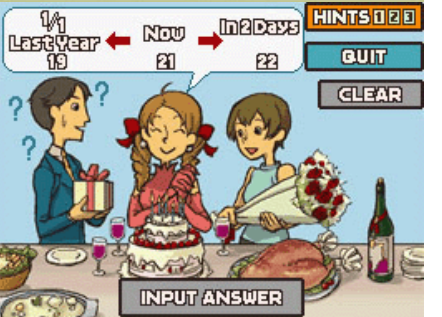

34	How Many Sheets?	<p><b>No.033</b>   <b>00 PICARATS</b>   <b>COINS : 55</b></p> <p>Several rectangular sheets of transparent film are arranged on top of each other as shown. The lines represent areas where one sheet overlaps with another.</p> <p>At the thickest point of this pile, how many sheets are overlapping?</p>  <p><b>HINTS 1 2 3</b></p> <p><b>QUIT</b></p> <p><b>CLEAR</b></p> <p><b>INPUT ANSWER</b></p>	Spatial	Ryu Lilo
56	The Lazy Guard	<p><b>No.036</b>   <b>80 PICARATS</b>   <b>COINS : 110</b></p> <p>The local museum has an exhibit that spans nine rooms, as shown in the diagram below. The entrance to the complex is marked by A, and the exit is marked by B.</p> <p>The security guard on duty is a bit of a loafer and wants to walk each room of the exhibit while turning <i>as few times as possible</i>. What is the <i>fewest number of turns he can make</i> while still visiting every room?</p> <p>As an example, the diagram below shows a course that involves six turns.</p>  <p><b>HINTS 1 2 3</b></p> <p><b>QUIT</b></p> <p><b>CLEAR</b></p> <p><b>INPUT ANSWER</b></p>	Spatial	Ryu Lilo



57	Cut Which One?	<p><b>No.037</b> 50 PICARATS COINS : 100</p> <p>Below are six linked rings.</p> <p>They may look like a tangled mess, but there is one ring that, if cut away, would leave the remaining five rings connected end to end in a long chain.</p> <p>Which one must you cut in order to make the chain? Choose one answer from below.</p>  <p><b>HINTS</b> 1 2 3</p> <p><b>QUIT</b></p>	Spatial	Ryu Lilo
59	The Longest Path	<p><b>No.039</b> 50 PICARATS COINS : 112</p> <p>Two boys are playing a game in which the goal is to take the <b>longest route possible from point A to point B</b>, as shown on the map below. The only rule is that <b>no section of road can be traversed more than once</b>.</p> <p>What course should they take in order to cover the longest distance possible between point A and point B?</p>  <p><b>HINTS</b> 1 2 3</p> <p><b>QUIT</b></p> <p><b>CLEAR</b></p> <p><b>SUBMIT</b></p>	Spatial	Ryu, Lilo, Kairi

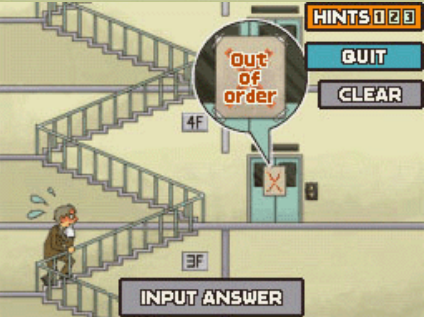
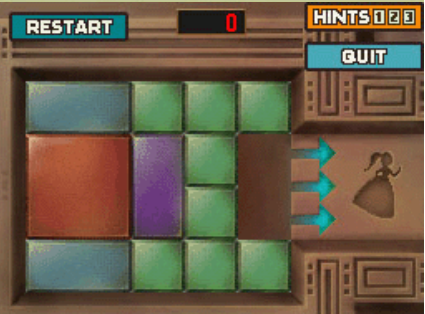


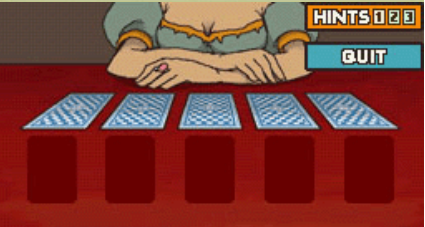





61	Pin Board Shapes	<p><b>No.061</b> 00 PICARATS COINS : 107</p> <p>The cross shape on the Pin board below has nine pins inside it and 16 outside it.</p> <p>Remember that example, because now it's your turn to construct a shape on the board. Can you create a cross that has 17 pins inside it and 16 outside it?</p> <p>Feel free to make your cross any size you like.</p> 	Spatial	Ryu, Kairi
62	The Mysterious Note	<p><b>No.062</b> 40 PICARATS COINS : 107</p> <p>A detective who was mere days from cracking an international smuggling ring has suddenly gone missing. While inspecting his last-known location, you find a note.</p> <p>The note appears to be nothing more than a series of numbers, but your gut instinct tells you that this note will reveal the name of the crime kingpin.</p> <p>Currently there are three suspects in the case: Bill, John, and Todd. Can you break the detective's code and find the criminal's name?</p> 	Hypothetical- deductive Lateral	Ryu, Kairi

63	How Old is Mom?	<p><b>No.063</b>    <b>20 PICARATS</b>    <b>COINS: 107</b></p> <p>A father and son are having a conversation. The father turns to the son and says:</p> <p>"You know, son, there was a time when your old man was twice the age of your mother. Of course, the next year, I was only one and a half times her age, but still, that's pretty amazing, eh?"</p> <p>If the father is 44 years old, how old is the mother?</p> 	Hypothetical-deductive	Ryu, Kairi
65	What's E?	<p><b>No.065</b>    <b>50 PICARATS</b>    <b>COINS: 119</b></p> <p>According to the diagram shown here, A=2, B=3, C=3, and D=4.</p> <p>So what does E equal?</p> 	Spatial	Ryu, Sora

66	Birthday Girl	<p><b>No.066</b>    <b>80 PICARATS</b>    <b>COINS : 119</b></p> <p>When asked about her birthday, a young woman gives the following information:</p> <p>"The day after tomorrow, I turn 22, but I was still 19 on New Year's Day last year."</p> <p>When is her birthday?</p> 	Hypothetical-deductive	Ryu, Sora
69	Chocolate Puzzle	<p><b>No.069</b>    <b>80 PICARATS</b>    <b>COINS : 121</b></p> <p>You have a hankering for chocolate, so you buy a huge sheet of 30 chocolate squares. The sheet is five squares long by six squares wide. You can only break the chocolate at the lines that run between squares, and you aren't allowed to stack multiple segments on top of each other.</p> <p>Keeping those rules in mind, what is the fewest number of times you'll need to break the chocolate in order to separate each of the 30 chocolate squares?</p> 	Hypothetical-deductive	Ryu, Sora


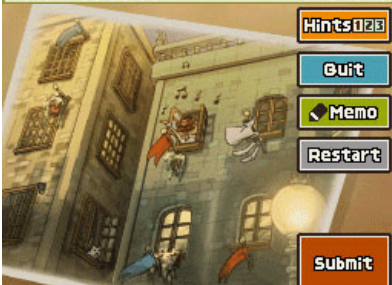
71	Sausage Thief	<p><b>No.071</b> 30 PICARATS COINS : 100</p> <p>Somebody ate the butcher's sausages! Here's what these four boys have to say:</p> <p>A: "B ate the sausages!"          B: "D ate them all up!"          C: "I didn't eat them, no way!"          D: "B's totally lying!"</p> <p>Only <b>one of these rascals is telling the truth</b> and all the others are, needless to say, lying. Can you figure out <b>who ate the sausages?</b></p> 	Hypothetical-deductive	Ryu, Sora
95	A Magic Square	<p><b>No.095</b> 30 PICARATS COINS : 100</p> <p>You need to solve this magic square in order to proceed.</p> <p>A magic square is a set of numbers organized in a square so that adding any string of three numbers, be they horizontal, vertical, or diagonal, results in the same total.</p> <p>One and two have already been placed on the square for you. Complete the rest of the square to open the lock.</p> 	Hypothetical-deductive Mathematical	Ryu, Sora, Lilo



96	Take the Stairs	<p><b>No.096</b> 80 PICARATS COINS : 100</p> <p>You have business on the eighth floor of a 10-story building. It took you 48 seconds to make your way from the first floor to the fourth.</p> <p>If you keep moving at the same speed, how long will it take you to reach the eighth floor from the fourth?</p> 	Proportional	Ryu, Sora, Lilo
97	Princess in a Box 1	<p><b>No.097</b> 60 PICARATS COINS : 105</p> <p>Tired of leading a sheltered life, this princess is trying to escape her castle. Armed guards, however, are blocking her path.</p> <p>Slide the blocks out of the way to move the red one out the exit to the right.</p> <p>Her freedom depends on you. Can you do it?</p> 	Sliding	Ryu, Lilo, Kairi, Sora

98	Card Order	<div><div>No.09870 PICARATSCOINS : 196</div><div>You've placed one Joker and four aces with different suits facedown on a table. Use the hints below to determine the position for each card.</div><div><div>1. The club is to the immediate right of the heart.</div><div>2. Neither the diamond nor the Joker is next to the spade.</div><div>3. Neither the Joker nor the diamond is next to the club.</div><div>4. Neither the diamond nor the spade is next to the heart.</div></div><div><div>HINTS123</div><div>QUIT</div><div></div><div><div></div><div>SUBMIT</div></div></div></div>	Combination	Ryu, Lilo, Kairi, Sora
99	33333!	<div><div>No.09970 PICARATSCOINS : 197</div><div>Use each of the numbers one through nine exactly once to fill in the blanks and complete this equation.</div><div>00000-0000=33333</div><div><div>RESTART</div><div>HINTS123</div><div>QUIT</div><div><div><div></div><div></div><div></div><div></div><div></div></div><div><div></div><div></div><div></div><div></div><div></div></div></div><div><div>33333</div><div>123456789</div></div><div>SUBMIT</div></div></div>	Mathematical	Ryu, Kairi, Lilo

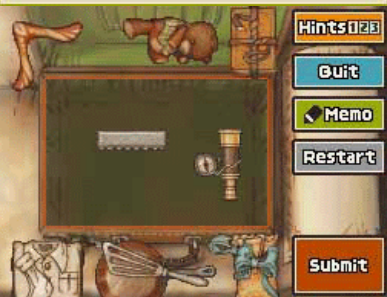





## APPENDIX E: PUZZLES PLAYED IN PROFESSOR LAYTON AND THE DIABOLICAL BOX



Number	Title	Screenshot	Type	Played by
1	Dr. Schrader's Map	<p><b>No.001</b>    <b>10/10 Picarats</b>    <b>Hint Coins: 10</b></p> <p>In the map to Dr. Schrader's home, several Pieces in the center have been cut out. Restore the map by inserting the missing Pieces in the correct spots.</p> <p>Touch a Piece with your stylus to grab it, then slide your stylus to move the selected Piece across the screen. You can't rotate the Pieces.</p> <p>It may sound simple, but don't forget that you can move or remove Pieces, including the one already in the middle of the map.</p> 	Spatial - Pattern	Ryu, Sora, Kairi, Peach, Lilo
2	The Doctor's Home	<p><b>No.002</b>    <b>15/15 Picarats</b>    <b>Hint Coins: 10</b></p> <p>Find Dr. Schrader's window from the details in his letter.</p> <p>"In the morning, I often awaken to the sound of music drifting in from a nearby flat. Looking out, I spy a flag fluttering gently outside my window, take a single sip of my tea, and turn my attention to the morning sun. Not many flats in London have a view of the sunrise anymore, you know."</p> <p>Circle the window from which the doctor views the sunrise.</p> 	Hypothetical-deductive	Ryu, Sora, Kairi, Peach, Lilo



3	The Right Key	<p><b>No.003</b>    <b>20/20Picarats</b>    <b>Hint Coins: 16</b></p> <p>Which key opens the door?</p> <p>As you might expect, the key won't open the door if its shape won't let it pass through the keyhole. Use your stylus to fit keys to the lock.</p> <p>Examine each key carefully and use your stylus to move the keys and find the one that fits into the lock.</p> 	Spatial	Ryu, Sora, Kairi, Peach, Lilo
4	A Secure Room	<p><b>No.004</b>    <b>30/30Picarats</b>    <b>Hint Coins: 16</b></p> <p>With its windows opening out into thin air eight stories up and its door securely bolted, you might think that this room is inaccessible from the outside. However, a single unusual detail reveals the truth of what went on here.</p> <p>Your job is to look around the room by tapping the arrows and find this detail. Once you've got it, circle the area with your stylus and choose Submit to give your answer. Make sure to circle only one object when you answer.</p> 	Hypothetical-deductive	Ryu, Sora, Kairi, Peach, Lilo


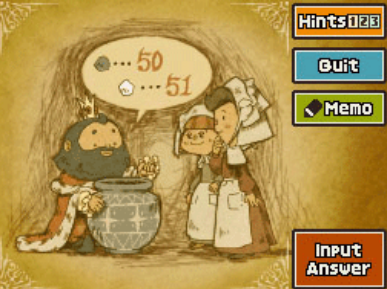


5	Luke's Trunk	<p><b>No.005 30/30Picarats Hint Coins: 19</b></p> <p>Luke's belongings are all over the place and need to be packed away in his trunk.</p> <p>Use your stylus to move individual objects into the trunk, and make sure that none of them overlap.</p> <p>When you think everything has been placed neatly into the trunk, tap Submit.</p> 	Spatial - Puzzle	Ryu, Kairi, Lilo
40	The Tiled Box	<p><b>No.040 30/30Picarats Hint Coins: 72</b></p> <p>The two boxes shown below are actually the same box shown from two different angles. Using the visible faces, reassemble the pattern of the box by placing the tiles into the unfolded view of the box.</p> <p>Don't forget, each tile needs to go in the correct square facing the correct direction.</p> 	Spatial	Ryu, Peach

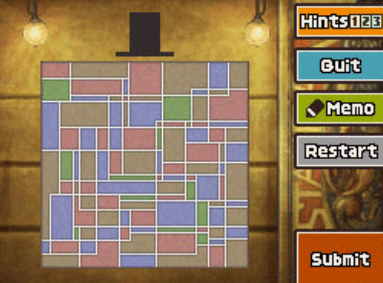

55	Sammy's Necklace	<p><b>No.055</b>   <b>30/30 Picarats</b>   <b>Hint Coins: 72</b></p> <p>Sammy has eight chains with seven links each. He wants to connect all these chains to make a totally awesome necklace that's a single loop. The Jeweler says he can open and close a single link for \$2.</p> <p>As shown below, Sammy could open an end of each of the eight chains to make one long necklace that's a single loop. However, that would cost \$16, and the truth is there's a cheaper way to get the same results. Using the cheapest method possible, how much will it cost to make Sammy's necklace?</p> 	Hypothetical-deductive	Ryu, Peach
56	The Door's Code	<p><b>No.056</b>   <b>40/40 Picarats</b>   <b>Hint Coins: 72</b></p> <p>In order to Pass through this door, Luke and Layton must arrange the symbols according to the following rules:</p> <ul style="list-style-type: none"> <li>-The star must be next to the moon.</li> <li>-The X must be second from the top.</li> <li>-The circle must be somewhere above the diamond.</li> <li>-The moon must be located two places below the diamond.</li> </ul> <p>Give it a shot!</p> 	Combination	Ryu, Peach



57	Smell the Roses	<p><b>No.057</b>   <b>30/30 Picarats</b>   <b>Hint Coins: 74</b></p> <p>Ah, there's nothing like fresh-cut roses to boost your spirits. Can you help Sammy freshen up the whole car with their fragrance?</p> <p>Tap a square with your stylus to place a rose. The fragrance of each rose reaches two spaces in all directions but can't penetrate walls. If the fragrance of two or more roses overlaps, the resulting smell will be overpowering, so make sure to keep your roses spaced out. To remove an existing rose, just tap on it again.</p> 	Spatial	Ryu, Peach
58	In the Tunnel	<p><b>No.058</b>   <b>35/35 Picarats</b>   <b>Hint Coins: 76</b></p> <p>Two trains pass in the darkness of the tunnel. Move them around so that each locomotive ends up on the opposing track while still maintaining the same order of its cars. There's one trick, though: the number 2 cars for both trains must remain in their original tracks.</p> 	Combination	Ryu, Peach

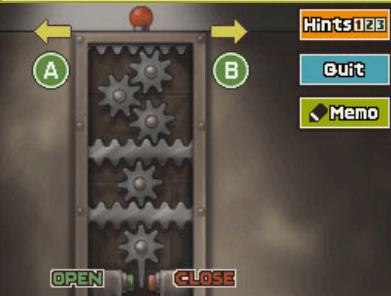

59	A Ticket to Where?	<p><b>No.059 40/40Picarats Hint Coins: 76</b></p> <p>In front of you sits the ticket that Layton and Luke found with Dr. Schrader. At first glance, the ticket appears to have no destination written on it. But when you look at it just the right way, the ticket discloses its destination: the town of Folsense.</p> <p>The key to spotting the destination is the <b>number</b> that has been cut out of the ticket. What number used to be there?</p> <p>Use the ticket in the instruction booklet to puzzle this one out!</p> 	Hypothetical-deductive Lateral	Ryu, Peach
61	Where's the Hotel	<p><b>No.061 30/30Picarats Hint Coins: 82</b></p> <p>In front of the town train station are four buildings standing in a row. One of these four is supposedly the local hotel, though it lacks a sign. Even so, if you study the area carefully, you should be able to tell which of the buildings is the hotel.</p> <p>Can you figure out which of these four buildings is the hotel?</p> 	Hypothetical-deductive Spatial Lateral	Ryu, Sora, Peach, Lilo

62	Smell the Roses Again	<p><b>No.062</b>    <b>40/40Picarats</b>    <b>Hint Coins: 88</b></p> <p>Nothing smells quite as sweet as fresh-cut roses. Can you help freshen up the whole room with their fragrance?</p> <p>Tap a square with your stylus to Place a rose. The fragrance of each rose reaches two spaces in all directions but can't penetrate walls. If the fragrance of two or more roses overlaps, the resulting smell will be overpowering, so make sure to keep your roses spaced out. To remove an existing rose, just tap it again.</p> 	Spatial	Ryu, Lilo
64	Stones in a Vase	<p><b>No.064</b>    <b>20/20Picarats</b>    <b>Hint Coins: 142</b></p> <p>"This vase holds 101 stones, each identical in size and feel. There are 50 black stones and 51 white stones. Now, put on this blindfold, reach in, and pull out as many stones as you like. When you're finished, if you've removed an equal number of black and white stones, you'll receive a number of gold Pieces equal to the number of stones you pulled out."</p> <p>How many stones should you remove to give yourself the best chance of removing equal numbers of stones while getting the most money possible?</p> 	Probability	Ryu, Lilo






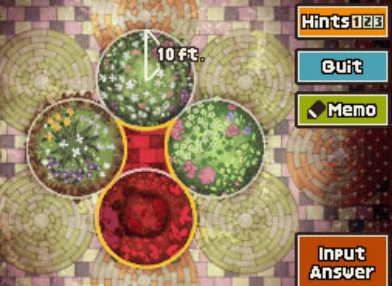
68	Hat Trick	<p><b>No.068</b>    <b>25/25Picarats</b>    <b>Hint Coins: 100</b></p> <p>Taking Felix's request for "that" hat at face value, you must now find another hat to hand over from the pattern shown below. The hat you're looking for will be the same shape and size as the one shown above the pattern, but it might not be facing the same direction.</p> <p>Use your stylus to outline your answer.</p> 	Spatial - pattern	Ryu, Sora, Lilo
69	Copying the Menu	<p><b>No.069</b>    <b>25/25Picarats</b>    <b>Hint Coins: 142</b></p> <p>The menu you see here has been folded into thirds with print on both sides, meaning in total there are six pages to it. The boss needs lots of copies, but your copy machine can copy a maximum of two adjacent menu pages at once. To save time, you want to complete a copy of the menu in as few passes through the machine as possible.</p> <p>What is the fewest number of Passes through the machine you need to make to create a full duplicate of the menu?</p> 	Combination	Ryu, Lilo



72	Scrambled Photos	<p><b>No.072</b>   <b>35/35 Picarats</b>   <b>Hint Coins: 100</b></p> <p>Four photographs decorate the wall of Joseph's Photo studio. Each photo depicts the same area and was taken at the exact same time of day. However, each photo was taken at a different point in time, and if you look carefully, you can figure out the order in which these pictures were taken. Enter your answer using the letters attached to each picture, starting with the earliest, like so: ABCD.</p> 	Spatial Hypothetical- deductive	Ryu, Sora, Lilo
77	Balancing Ornaments	<p><b>No.077</b>   <b>30/30 Picarats</b>   <b>Hint Coins: 187</b></p> <p>Small ornaments dangle from a metal bar, and they've thrown the bar off balance.</p> <p>The five ornament strings are spaced equally apart, and each of the three types of ornaments weighs a different amount. The heaviest ornament weighs the same as three of the lightest ones, while a medium ornament weighs the same as two of the lightest ornaments.</p> <p>Place one of the three ornaments in the rectangle in the space marked with a question mark to restore the bar's balance.</p> 	Proportional	

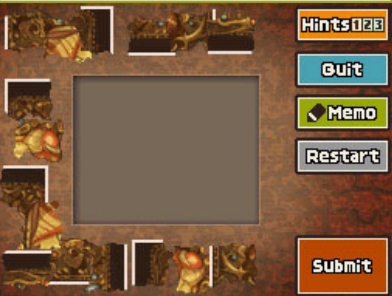

79	The Gear Switch	<p><b>No.079</b>    <b>20/20Picarats</b>    <b>Hint Coins:178</b></p> <p>The button that opens the door in front of you is buried deep within this machine, so you can't push it directly. However, by pulling the knob at the top to the left or right, you can move the various gears and plates in the machine, allowing you to press the button at the bottom.</p> <p>In order to hit the OPEN button, should you pull the knob toward A or B?</p> 	Physics	Ryu, Sora
80	The Elevator Switch	<p><b>No.080</b>    <b>40/40Picarats</b>    <b>Hint Coins:184</b></p> <p>The circuit board for the elevator contains a puzzle. According to the instructions, you need to make the blue and red balls switch places in order to restore power to the elevator. Are you up to the task?</p> 	Sliding	Ryu, Sora


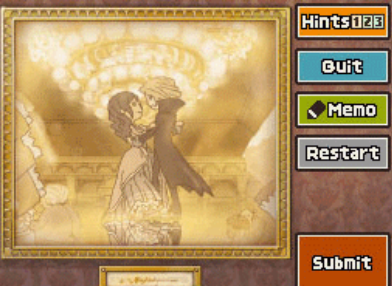


81	The Old Safe	<p><b>No.081</b>   <b>50/50Picarats</b>   <b>Hint Coins:137</b></p> <p>Find the four-number code that opens the safe. You can use the numbers zero through five in your answer, but each number can be used only once. The small lights next to each row of numbers are the key to finding the code, as they tell you how much in common that row has with the final code. Each white light indicates a number that matches one in the code but is in a different place within the sequence. An orange light indicates a number that is in the code and in its correct spot. Tap the numbers at the bottom to enter the code.</p> 	Combination	Ryu, Sora
82	Restarting the Lift	<p><b>No.082</b>   <b>30/30Picarats</b>   <b>Hint Coins:137</b></p> <p>The wires connecting the elevator to the button controlling it have somehow been severed. However, if you can connect the negative (-) and positive (+) wires on the top to the wires carrying the same charge below, you can fix the elevator. To do this, you need to draw lines between sets of X-shaped terminals. Draw two lines to connect each positive and negative terminal to its counterpart and get the elevator running again.</p> 	Spatial - Pattern	Ryu, Sora, Kairi



87	Different Suits	<p><b>No.087 40/40Picarats Hint Coins: 139</b></p> <p>Below are 16 cards. There are four cards from each suit: diamonds, clubs, spades, and hearts. The cards are arranged in a four-by-four grid as shown below, and four cards have already been put down.</p> <p>Arrange the remaining cards so that each vertical column, horizontal row, and <b>diagonal line</b> of four cards contains one card from each suit. Tap a space to place a card there or to change a card's suit.</p> 	Combination	Ryu, Sora
89	Flower Bed Fun	<p><b>No.089 40/40Picarats Hint Coins: 97</b></p> <p>Here are four circular flower beds, each with a radius of 10 feet. The way they're arranged forms a space between them. Can you find the area in square feet of the section colored red below?</p> <p>Ignore the width of the border around the flower beds when calculating your answer.</p> 	Math Reasoning Spatial	Ryu, Sora, Lilo



98	Jars and Cans 1	<p><b>No. 098</b>    <b>25 / 25 Picarats</b>    <b>Hint Coins: 142</b></p> <p>A long line of jars and cans sits on the counter. Your job is to rearrange these items so that both jars and cans are grouped with items of the same type. However, in doing so, you must always move two containers at once.</p> <p>Move items around by touching the red icon between two containers and dragging the selected pair of items around with your stylus.</p> 	Combination Logic	Ryu, Lilo
107	The Knight's Tour 2	<p><b>No. 107</b>    <b>50 / 50 Picarats</b>    <b>Hint Coins: 160</b></p> <p>Lead the knight on a trip around the board below.</p> <p>Chess knights move two squares forward and one square perpendicular on each turn. The initial direction can be up, down, left, or right.</p> <p>Move this knight around the entire board, landing on each square only once.</p> 	Spatial	Ryu, Sora


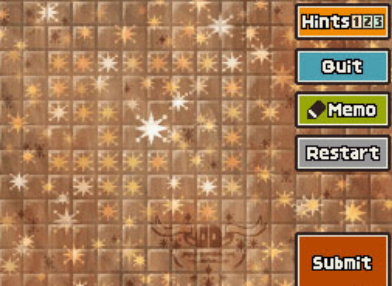
116	The Torn Photo	<p><b>No. 116</b>    <b>60/60 Picarats</b>    <b>Hint Coins: 130</b></p> <p>Professor Layton and Luke have finally hunted down all 16 pieces of that peculiar photo. Reassemble the pieces to reveal the contents of the image! Rotate a piece by touching a side and spinning it around.</p> <p>Be careful not to reassemble the picture upside down!</p> 	Puzzle	Ryu, Lilo
121	Light the Forest 1	<p><b>No. 121</b>    <b>20/20 Picarats</b>    <b>Hint Coins: 190</b></p> <p>Use lamps to light up the dark forest paths! For each lamp, assume its light reaches to the end of any straight road. Use the fewest lamps possible to light all of the paths.</p> <p>So where should the lamps go?</p> 	Spatial	Ryu, Kairi

125	Forest Mushrooms	<p><b>No. 125</b>    <b>50/50 Picarats</b>    <b>Hint Coins: 193</b></p> <p>Collect all of the mushrooms in this forest as you pass through. Each circular clearing on the map contains mushrooms.</p> <p>You don't want to spend too long in this creepy forest though, so find the quickest route through that visits each clearing only once.</p> <p>Stay on the roadways.</p>  <p>Hints 123  Quit  Memo  Restart  Submit</p>	Spatial	Ryu, Kairi
130	The Strange Painting	<p><b>No. 130</b>    <b>30/30 Picarats</b>    <b>Hint Coins: 209</b></p> <p>The couple in this piece seem to be dancing high in the air, floating impossibly near the chandelier. But as it turns out, when viewed properly, there's nothing strange at all about the picture. If you look closely enough, one peculiar area of the painting hints at the reason the whole picture seems so odd.</p> <p>Find that peculiar area and circle it to learn the truth.</p>  <p>Hints 123  Quit  Memo  Restart  Submit</p>	Spatial Hypothetical- deductive	Ryu, Peach



131	How to Escape?	<p><b>No. 131</b> 40/40 Picarats <b>Hint Coins: 209</b></p> <p>A man sits bound by a long length of rope among several posts. While he has no hope of untying his bonds, he can still move his legs. Were he to stand up and run away, his long trail of rope looks like it might catch on at least one of the posts.</p> <p>He'll need to use his legs to pull up any posts that prevent him from running away before he can dash off. Mark any posts that prevent the man from running away.</p> 	Spatial	Ryu, Peach
132	Sharing Paintings	<p><b>No. 132</b> 40/40 Picarats <b>Hint Coins: 230</b></p> <p>Two brothers have inherited their parents' five-piece art collection. According to the will, the older brother will get a set of paintings worth twice what the younger brother gets. In order to ascertain the value of the paintings, the brothers called in an appraiser, who valued each painting as shown below. For his services, the appraiser was promised the one painting left over after the brothers divided the art according to their parents' wishes.</p> <p>Assuming that individual paintings can't be divided, which one does the appraiser get?</p> 	Hypothetical- deductive Mathematical	Ryu, Peach

133	Grab the Key	<p><b>No. 133</b> 60/60 Picarats Hint Coins: 212</p> <p>The key to the door is sitting behind a number of blocks. Slide the key out toward the Professor's hand so the two can make their escape!</p> 	Sliding	Ryu, Peach
134	Steam Power	<p><b>No. 134</b> 40/40 Picarats Hint Coins: 215</p> <p>Which valves do you need to open to send steam from the boiler into 2, but not 1 or 3?</p> <p>All valves start in the closed position. Answer using the solution that requires opening the fewest number of valves. Tap a valve to open or close it.</p> 	Spatial	Ryu, Peach

135	The Magic Lock	<p><b>No. 135</b> 50/50 Picarats <b>Hint Coins: 221</b></p> <p>It seems that the lock here is some sort of magic square. In order to solve it, position the remaining numbers so that each string of four vertical, horizontal, and diagonal numbers adds up to the same total.</p> <p>Solve the magic square to open the door!</p> 	Hypothetical-deductive Mathematical	Ryu, Peach
136	The Hidden Door	<p><b>No. 136</b> 40/40 Picarats <b>Hint Coins: 224</b></p> <p>"Begin from the doors etched in the decor."</p> <p>"A path will appear, strong and quite clear,"</p> <p>"Made of stars that flare, each within its own square."</p> <p>These words are said to point the way to the hidden door. Select the hidden door.</p> 	Spatial	Ryu, Peach



## **APPENDIX F: INTERVIEW QUESTIONS**

1. What did you like about playing each of the games?
2. What didn't you like about playing each of the games?
3. What kinds/types of strategies or processes did you use while playing?
4. Did you get "stuck" at any point in any of the games? How did you get unstuck?
5. Did you have any "Aha!" moments while playing? When did they occur? Can you describe them?
6. What do you think you learned (or did you learn anything) from playing the games? It doesn't need to be strictly academic skills but can be anything.
7. Do you think what you have learned playing the games could be used in your classes? What about other situations? How?
8. Is there anything else you'd like to share about your game-playing experience?

**APPENDIX G: SAMPLE OUTLINE FOR GAME JOURNAL**

Date:	
Time Started:	
Time Ended:	
Game Played:	
Description of part of game played (if PLCV or PLDB, which puzzles did you attempt?):	
Did you get stuck at any point? How did you get unstuck?	
Did you use any hints provided by the game?	
Did you go online to try and find answers?	
Did you ask for any help from others?	
What, if anything, did you learn from playing during this session?	
Reflect on your game playing experience this session.	

**APPENDIX H: CODES AND DESCRIPTIONS**

<b>Code</b>	<b>Description</b>
Guessing	Participant uses phrases like “I guess...”
Trial and Error	Participant uses phrases like “I’ll try...” or demonstrates trying different things while relying on the game for feedback
Probabilistic Reasoning	Participant uses or displays evidence of probabilistic reasoning
Proportional Reasoning	Participant uses or displays evidence of proportional reasoning
Mathematical Reasoning	Participant uses mathematical knowledge or processes
Metacognition	Participant shows evidence of metacognition.
Evaluating/Judging	Participant evaluates their solution or process, such as “That’s not right” or “This is the solution.”
Predicting	Participant predicts or anticipates what the solution will be.
Planning a Strategy	Participant plans out strategy “I’ll do this, then I’ll do this...”
Working Backwards	Participant starts from the ending conditions and moves towards the initial conditions
Game Text	Participant reads the text provided by the game, such as instructions and hints.
Game Interaction	Participant interacts and comments on the game. “Oh no! Not the Baron!”
Not Relevant	Participant is off-task and not talking about the game or anything related to the game.
Self-esteem comments	Participant comments on their abilities. “I’m no good at...”
Double-checking	Participant checks solution before submitting.
Self-thinking/self-monitoring	Participant mentions their cognitive state. “I’m confused.” “I don’t know.” “I don’t understand.”
Game action	Participant is verbalizing what they are doing in the game, such as moving a piece.
Errors	Participant makes an error, such as the sun rises in the West.
Game questions	Participant is asking a question about the game, like “How do I select an answer?”

**APPENDIX I: PLCV: TIME TO SOLVE PUZZLES**

Puzzle	Sora	Kairi	Lilo	Peach	Ryu
1	0:01:09	0:01:20	0:01:15	0:04:30	0:01:02
2	0:01:53	0:01:13	0:00:36	0:01:06	0:01:10
3		0:04:06	0:00:39	0:01:56	0:03:33
4	0:05:06	0:09:33	0:04:44	0:01:29	0:01:38
6	0:05:11	0:07:16	X	0:02:08	0:03:08
7	0:13:35	0:04:35	0:07:37	0:08:25	0:04:41
9	0:01:00	0:06:21		0:03:17	0:02:58
12			0:04:29		0:14:50
34			0:07:42		0:01:53
56			0:10:04		0:13:13
57			0:03:21		0:01:27
59		0:05:40	0:24:46		0:12:35
61		0:11:11			0:07:38
62		0:10:16			0:01:39
63		0:07:30			0:01:53
65	0:29:58				0:01:16
66	0:03:31				0:17:15
69	0:21:16				0:04:04
71	0:08:52				0:01:47
95	0:08:04		0:02:49		0:11:30
96	0:04:47		0:03:24		0:01:55
97	0:19:13	0:15:09	0:29:50		0:03:30
98	0:02:01	0:02:40	0:04:11		0:02:37
99		0:04:03	0:09:06		0:11:22

**APPENDIX J: PLDB: TIME TO SOLVE PUZZLES**

Puzzle	Sora	Kairi	Lilo	Peach	Ryu
1	0:02:02	0:02:06	0:02:34	0:02:46	0:02:21
2	0:04:12	0:02:11	0:01:16	0:02:38	0:00:54
3	0:00:48	0:02:14	0:00:51	0:01:26	0:00:49
4	0:02:07	0:02:29	0:02:36	0:05:25	0:01:23
5		0:01:47	0:01:36		0:12:26
40				0:07:39	0:05:19
55				0:03:10	0:05:32
56				0:00:48	0:01:05
57				0:00:55	0:02:27
58				0:01:58	0:01:49
59				0:02:56	0:04:18
61	0:00:30		0:00:38	0:02:32	0:02:25
62			0:02:44		0:02:55
64			0:01:00		0:06:47
68	0:10:33		0:11:41		0:04:26
69			0:03:36		0:03:16
72	0:11:32		0:04:48		4:00:00
77	0:04:04	0:05:54			0:03:03
79	0:01:32				0:01:33
80	0:01:50				0:02:30
81	0:04:09				0:02:57
82	0:02:47	0:02:31			0:01:34
87	0:02:36				0:02:49

Puzzle					
	Sora	Kairi	Lilo	Peach	Ryu
89	0:10:13		0:08:49		0:25:26
98			0:01:28		0:02:28
107	0:13:52				0:08:18
116			0:05:34		0:03:46
121		0:02:46			0:01:13
125		0:10:43			0:13:48
130				0:01:10	0:00:45
131				0:07:18	0:04:01
132				0:05:21	0:03:20
133				0:11:36	0:01:42
134				0:03:39	0:02:19
135				0:03:57	0:05:37
136				0:06:47	0:01:23